報告・資料

Calculation of mark coordinates in 400 m oval athletics tracks: for enhancing performance analysis

陸上競技 400 m トラックのマーク座標計算：パフォーマンス分析の拡充にむけて

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Abstract : Performance analysis in racing disciplines, also known as race analysis, involves measuring split or lap times at specific positions or distances. Official times provide some data, but more detailed measurements must be taken for precise analysis. Filming with appropriately positioned cameras can detect athletes' passage at specific positions. Therefore, many studies have used that method for detailed event timing and race analysis. Nevertheless, the absence of marks indicating certain positions poses challenges. Geometric calculations can compensate for missing marks, but the calculations entail intensive effort. In this study, we examined methods for calculating mark coordinates of 400 m oval athletics tracks. Thereafter, the calculated results for two tracks with typical layouts were presented. Furthermore, two application examples for identifying additional analysis-point positions were demonstrated. No marks exist for some analysis-point positions, but this method allows calculation of appropriate positions and supports detailed race analysis.

Key words : track mark coordinates, geometric calculation, homography matrix, analysis-point projection, race analysis

キーワード：トラックマーク座標, 幾何学計算, ホモグラフィ行列, 分析ポイント投影, レース分析

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受付日：2024 年 8 月 16 日

受理日：2025 年 2 月 13 日

Ⅰ. Introduction

Performance analysis in racing disciplines, i.e., race analysis, often involves event timing, which entails measurement of split or lap times at specific positions or distances. This approach is applicable to a range of sports such as athletics[1), 7), 9)], swimming[3)], cycling[4)], rowing[5)], and speed skating[8)]. Such analyses are instrumental in identifying key factors for winning races and optimizing athletes' performance. In races of some sports, times at specific distances are measured officially, e.g., 100 m split times in athletics[9)], 250 m split times in cycling[4)], and 400 m lap times in speed skating[8)]. Although these official times are useful for analyses, more detailed time measurements are expected to be necessary to achieve more precise analysis. Therefore, analysts often attempt to undertake additional timing[1), 3)].

Time measurement techniques encompass timing cells[6)], lasers[7)], filming[1), 3), 6)], and others. Timing cells are devices designed to detect the time of a gate passage. By placing them at predetermined positions, an observer can obtain the split time at these positions and the lap times between gates. The spatial resolution of timing depends on the number of gates installed. However, expanding their number presents practical limitations in terms of cost. Additionally, it is often difficult to install them on a race course for competitions. Laser apparatus (e.g., LAVEG Sport; Jenoptik, Germany[7)]) can measure the one-dimensional position of athletes continuously at frequencies of 50–100 Hz. From the measured data, one can ascertain the time of an athlete's passage at given positions or calculate the instantaneous velocity of the athletes. As with photocells, the important limitation of the laser apparatus is related primarily to its feasibility of installation on race courses.

Filming is a practical method for timing analysis that is useful for competitions. From films taken of athletes, one can detect the time of their passage at given positions. This time measurement requires no installation of any device on race courses, but it necessitates films taken of the athletes competing on the race course from a proper angle for analysis. Athletes in several disciplines have been analyzed using this technique[1), 3), 6)]. When using filming for time measurements, two conditions must be met. First, the filming must be conducted with appropriately positioned cameras so that the passage of athletes at given timing positions can be determined accurately. An ideal camera angle is almost perpendicular to the athletes' direction of movement. Second, the positions for time measurements must be recognizable in the films. Marks installed in accordance with competition regulations (e.g., known distance start-lines, hurdle position marks, and relay takeover zone lines in athletics[6)], or colored course slopes in swimming[3)]) are often used for analysis position recognition. Some researchers have reported that they used additional marks to achieve detailed time measurements[6)]. In theory, comprehensive precise measurement can be achieved by increasing the number of timing positions. In practice, however, one must consider the effort necessary for additional mark installation and its compliance with competition regulations. To facilitate further detailed analyses, practical methods to overcome this absence of marks should be proposed.

For studies of certain sports such as football, researchers have used coordinate calculations to determine the athletes' positions on the playing field while referencing the field lines[2)]. This approach inspires us to use a similar calculation to compensate for the absence of marks on analysis positions. For this calculation, reference marks with known positions are necessary to develop the coordinate system. For race courses that are aligned in a predetermined and simple layout, with a straight stretch such as that of a 50 m swimming pool, the coordinate system can be developed with relative ease[3)]. However, in cases where race courses are aligned in a complex or not strictly regulated layout, developing the coordinate system becomes more challenging.

An example of such a challenge is a 400 m oval athletics track. The track layout is not solely standardized in terms of bend radii and straight length, leading to variations in coordinates of the marks, such as echelon-starting and group-starting start lines and hurdle position marks in curves, by venue. It is certainly possible to calculate the coordinates geometrically by referencing the facility regulation guidelines issued by the athletics association, but this process can be complicated and time-consuming. Therefore, in this study, we aimed at providing a comprehensive description of the calculation methods of mark coordinates on 400 m oval athletics tracks, along with a demonstration of typical calculation results as a reference for future research. Furthermore, we demonstrated identification of the analysis-point positions with the calculated mark coordinates and subsequently examined its accuracy.

Ⅱ. Methods

1. Review of the regulations

To determine the calculation methods of mark coordinates, it is imperative to gain an understanding of the regulations which govern the layout of athletics tracks. The regulation is established by World Athletics (WA) and is described in WA's facilities manual[10]. The key contents can be summarized as presented below.

a. The lap length is 400 m, along the running line in lane 1. The ratio of straight and curve sections depends on the specifications of the constructed track.

b. Suitable bend radii range of 35 and 38 m, with an optimum radius of 36.50 m. A single bend radius less than 33.50 m and the running line radius on the outer lanes over 50 m will not be certified. Double bend tracks, i.e., curves formed with two radii, are not recommended and would not be approved for major competitions.

c. The inside edge of the track should have a kerb around the bends and optionally on the straights, with 0.05–0.065 m height and 0.05–0.25 m width. A kerb with the respective height and a width of 0.05 and 0.05 m is the most common in practice.

d. All lanes have width of 1.22 m, including a 0.05-m wide white line on the outer side. It is noteworthy that tracks constructed before 1 January 2004 might have a lane with of maximum 1.25 m.

e. The theoretical running line, also called the measurement line, is set at a distance of 0.30 m outward from the kerb in lane 1. Those in outer lanes are set at 0.20 m from the outer edge of the adjacent inside lane.

f. All race distances are measured along the measurement line of each lane in a clockwise direction, i.e., back from the finish line, from the edge of the finish line nearer to the start to the edge of the start line farther from the finish.

g. All start and finish lines, except for group-starting start lines, are marked in individual lanes perpendicular to the lane lines, with 0.05 m width.

h. Start lines for group starting in 1500 m, 5000 m, and 10000 m races are marked to ensure that the distance along the shortest permitted route satisfies the race distance irrespective of the starting position on the start line. The shortest route is attained along the tangent line of the curve ahead.

i. For 800 m and 4×400 m relay races, the route is separated to each lane initially. Later, it becomes opened in the middle of the race. The transition point from the separated lanes to the opened lane is shown with a break line, which is marked immediately after the end of the first curve, ensuring that the distance along the shortest permitted route going over the second curve, i.e., the tangent line length of the second curve from the break line plus the subsequent arc length of the curve, is constant. Thereafter, the start lines are marked with the “reduction” distance considered, i.e., from the exit of the first curve to the break line on the hypotenuse tangent line of the second curve. Reportedly, the reduction distance is not measured strictly along the theoretical running line but along the hypotenuse line. Therefore, it does not necessarily equal the required reduction along the measurement line.

j. In 5000 m and 10000 m races, group starting can be conducted in two separate groups: one from inside lanes and one from the outside over 5 lanes. The outer group runs along lane 5 only in the initial curve section and joins the inner group after passing the breakpoint, which is placed on the intersection of the break line and the inside lane line of lane 5 for the 10000 m race, or placed in the entrance of the home straight section on the same lane line for the 5000 m race. The inside line for the outer group shall be marked with cones or flags, or with temporary kerbing, placed on the line from the start to the breakpoint. If this inside line is marked with cones or flags, then the running line is considered to be 0.20 m outward from the line. The inside root of the start line of 10000 m will coincide with the 800 m start line. If, by contrast, the inside line is marked with the temporary kerb, then the running line is considered to be 0.30 m outward from the line. Therefore, the root of the start line of 10000 m will be located slightly forward of the 800 m start line. The 5000 m start line will be located forward of the 200 m start line whether the temporary kerb is used or not, although it will be further ahead if the kerb is used.

k. Hurdle positions in 110 m hurdle, 100 m hurdle, and 400 m hurdle races are marked on the track by the lines with the respective length and width of 0.10 and 0.05 m, both inside and outside of each lane. These marks are located so that the distance measured from the start to the edge of the line nearer to the start satisfies the regulated hurdle intervals. The interval distance between hurdles in 110 m hurdle race is 9.14 m, with a 13.72 m approach run and a 14.02 m run-out to the finish. Those in 100 m hurdles are 8.50 m, 13.00 m, and 10.50 m, respectively, for intervals, approach run, and run-out. Furthermore, those in 400 m hurdle are, respectively, 35 m, 45 m, and 40 m.

l. In a 3000 m steeplechase race, the positions of start line, hurdles, and the water jump depend on the water jump pit layout. The water jump pit shall be installed inside or outside the track in the second curve.

A WA recommendation is that all further tracks be constructed according to the specifications designated as “400 m Standard Track”, which are presented in Table 1. However, a number of tracks have been constructed to different specifications for venue-specific reasons.

2. Calculation of track mark coordinates

Positions of the marks in each lane are calculable with the track layout regulations and specifications using the following steps. In this study, the positions of the marks are defined as the intersection of the edge of the mark farther from the finish line and either the outer edge of the inside lane line or the inner edge of the outside lane line of each lane (Figure 1). It is noteworthy that the coordinates described below are expressed in the provisional coordinate system with the origin set at the intersection of the finish line and the

Table 1. Specifications of the “400 m Standard Track”.[10)]

Length of straight	84.390
Construction radius of bend (inside edge of track with raised kerb)	36.500
Radius of measurement line in lane1 (0.30m outside from the inside edge of track)	36.800
Width of each lane	1.220

unit: m

kerb edge, the *x*-axis along the finish line toward the outside direction, and the *y*-axis along the measurement line in the home straight section toward its running direction. All calculation values below are given in meters and radians. In the following descriptions, the regulations used for mark coordinates calculation are indicated by the alphabet listed in the above regulation review, for example, with the notation “*R-a*”. The basic parameters and track section names used in the calculations are presented in Figure 2.

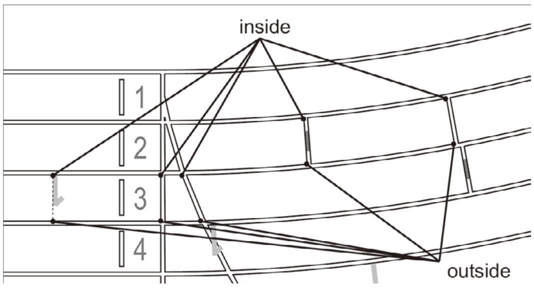
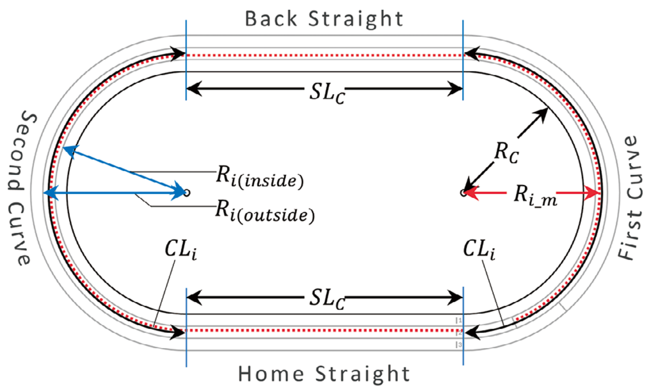


Figure 1. Definitions of coordinates of marks.
The “inside” denotes the intersection of the mark edge farther from finish line and the outer edge of the inside lane line, whereas the “outside” denotes the intersection of the mark edge and the inner edge of the outside lane line.

a. Before the calculation, the length of parallel straights (SL_C, Figure 2) must be ascertained with reference to the track specification document, or by direct measurement of the length. One useful means for measuring SL_C is to use the breakpoint at the entrance to the home straight (*R-j*). In actuality, SL_C coincides with the distance between the breakpoint and the finish line. By measuring the distance from the breakpoint to the nearest hurdle mark, e.g., the second hurdle mark for 100 m hurdle, which is located at 78.5 m distance from the finish line (*R-k*), SL_C can be determined with ease.

b. The construction radius of a bend (R_C, from the center of the first curve to the inside edge of the track with the raised kerb, Figure 2) can be de-



SL_C : Construction length of straights.
R_C : Construction radius of bends (radius of the kerb).

R_{i_m} : Radius of the curved measurement line in lane i.
CL_i : Length of the semicircle arc along the curved measurement line in lane i.

R_i : Radius of the edge of the lane line in lane i (either the outer edge of the inside lane line or the inner edge of the outside lane line can be used).

Figure 2. Schematic diagram of the athletic track and list of the terms used for describing track specifications.

rived from the length of parallel straights (SL_C) as

$$R_C=(400.000-2*SL_C)/(2*\pi)-0.300, \quad (1)$$

where 400.000 is the distance of a lap of the measurement line in lane 1 (*R-a*), 0.300 is the distance between the kerb and the measurement line in lane 1 (*R-e*), and π represents pi, i.e., 3.1415⋯.

c. The length along the measurement line on each curve section of each lane is calculable as shown below.

$$R_{1\_m}=R_C+0.300 \quad (2)$$

$$R_{i\_m}=R_C+1.220*(i-1)+0.200 \quad [i\geq 2] \quad (3)$$

$$CL_i=R_{i\_m}*\pi \quad (4)$$

In those equations, R_{i_m} and CL_i respectively represent the radius of the curved measurement line and the semicircle arc length along the curved measurement line. Subscript i represents the lane number. The value of 0.300 is the distance between a kerb and the measurement line in lane 1, whereas 0.200 is the distance between the outer edge of the inside lane line and the measurement line in lanes 2 and outer (*R-e*). The value of 1.220 is the lane width (*R-d*).

d. The section in which the mark is located, i.e., first curve, back straight, second curve, and home straight (Figure 2), can be found by referring the distance back from the finish line to the mark. Within this section, the distance back from the end of section to the mark (D_i) must be calculated. It is used for the following calculations. It is noteworthy that the start lines of 100 m and 110 m hurdles, and hurdle marks of 100 m and 110 m hurdle races are all treated as located in the home straight section, even though D_i exceeds SL_C.

e. For calculation of the coordinates of the marks located in the curve sections, the radius of the kerb or lane line edges (R_i, Figure 2) must be determined first. When the intersection of the mark and the outer edge of the adjacent inside lane line, and the edge of the kerb in the case of lane 1, is of interest, the radius is expected to be the following.

$$R_{i(inside)}=R_C+1.220*(i-1) \quad (5)$$

Regarding the inner edge of the outside lane line, the radius is expected to be the following.

$$R_{i(outside)}=R_C+1.220*(i-1)+1.170 \quad (6)$$

In those equations, 1.220 is the lane width. Also, 1.170 is the value subtracting the lane line width of 0.050 from the lane width (*R-d*). Thereafter, the coordinates of the marks in the first curve section are calculable as shown below.

$$\varphi_i^{(1)}=\pi*\left(\frac{CL_i-D_i}{CL_i}\right) \quad (7)$$

$$P_{i\_x}=-R_C+R_i*\cos\{\varphi_i^{(1)}\} \quad (8)$$

$$P_{i\_y}=R_i*\sin\{\varphi_i^{(1)}\} \quad (9)$$

Therein, $\varphi_i^{(1)}$ signifies the angle formed by the extension lines of the mark and the entrance of the curve section, which intersects at the center of the curve (Figure 3). P_{i_x} and P_{i_y} respectively represent the x-coordinates and y-coordinates of the intersection of the mark and the edge of the lane line. Any value of $R_{i(inside)}$ or $R_{i(outside)}$ can be used for R_i. In a similar manner, the coordinates for the marks located in the second curve section can be found.

$$P_{i\_x}=-R_C-R_i*\cos(\varphi_i^{(1)}) \quad (10)$$

$$P_{i\_y}=-SL_C-R_i*\sin(\varphi_i^{(1)}) \quad (11)$$

f. The coordinates of the marks located in the home straight section can be ascertained using the same parameters as those above.

$$P_{i\_x}=-R_C+R_i \quad (12)$$

$$P_{i\_y}=-D_i \quad (13)$$

Similarly, those in the back straight section can be determined as presented below.

$$P_{i\_x}=-R_C-R_i \quad (14)$$

$$P_{i\_y}=-SL_C+D_i \quad (15)$$

g. For calculating the coordinates of the start lines of the 800 m and 4×400 m relay, D_i must be determined with the reduction distance (RD_i) considered (*R-i*). The value of RD_i is calculable as shown hereinafter (Figure 4).

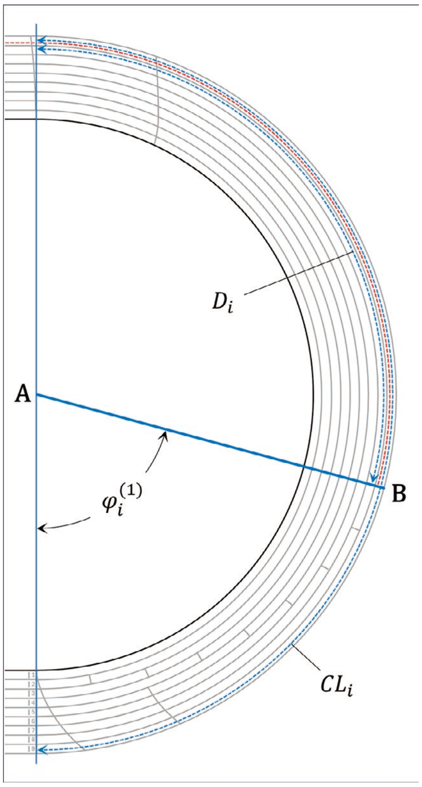


Figure 3. Calculation of the coordinates of the intersection of the mark and each lane line edge in curve sections. **A** is the center of the curve. **B** is the intersection of the mark and the lane line edge in lane i, which can be either on the outer edge of the inside lane line or on the inner edge of the outside lane line. CL_i denotes the length on the semicircle measurement line in lane i. D_i expresses the length on the curved measurement line from the mark to the end of the curve section in lane i. $\varphi_i^{(1)}$ signifies the angle formed by line **AB** and the entrance line of the curve section. i stands for lane number ($i \geq 1$). This figure shows the case of $i = 9$, the intersection of the 400 m start line and the inner edge of the outside lane line.

$$K_i^{(2)} = \sqrt{SL_C{}^2 + R_{i\_m}{}^2} \tag{16}$$

$$\alpha_i^{(2)} = \cos^{-1}\left(\frac{R_{1\_m}}{K_i^{(2)}}\right) \quad [0 < \alpha_i^{(2)} < \pi/2] \tag{17}$$

$$\beta_i^{(2)} = \tan^{-1}\left(\frac{SL_C}{R_{i\_m}}\right) \quad [0 < \beta_i^{(2)} < \pi/2] \tag{18}$$

$$\gamma_i^{(2)} = \alpha_i^{(2)} - \beta_i^{(2)} \tag{19}$$

$$ArcL_i^{(2)} = R_{1\_m} * \gamma_i^{(2)} \tag{20}$$

$$H_i^{(2)} = \sqrt{K_i^{(2)2} - R_{1\_m}{}^2} \tag{21}$$

$$RD_i = H_i^{(2)} - ArcL_i^{(2)} - SL_C \tag{22}$$

In those equations, $K_i^{(2)}$, $\alpha_i^{(2)}$, $\beta_i^{(2)}$, $\gamma_i^{(2)}$, $ArcL_i^{(2)}$, and $H_i^{(2)}$ represent the lengths and angles defined in Figure 4.

h. The coordinates of the intersection of the break line and each lane line edge are obtainable by calculating $L_i^{(3)}$ as defined in Figure 5. With a given $L_i^{(3)}$, the length of the tangent hypotenuse running line from the intersection of the break line and the lane line edge ($H_i^{(3)}$) can be described in two ways. The first is the following (Figure 5).

$$K_i^{(3)} = \sqrt{L_i^{(3)2} + R_i{}^2} \tag{23}$$

$$\alpha_i^{(3)} = \cos^{-1}\left(\frac{R_{1\_m}}{K_i^{(3)}}\right) \quad [0 < \alpha_i^{(3)} < \pi/2] \tag{24}$$

$$\beta_i^{(3)} = \tan^{-1}\left(\frac{L_i^{(3)}}{R_i}\right) \quad [0 < \beta_i^{(3)} < \pi/2] \tag{25}$$

$$\gamma_i^{(3)} = \alpha_i^{(3)} - \beta_i^{(3)} \tag{26}$$

$$ArcL_i^{(3)} = R_{1\_m} * \gamma_i^{(3)} \tag{27}$$

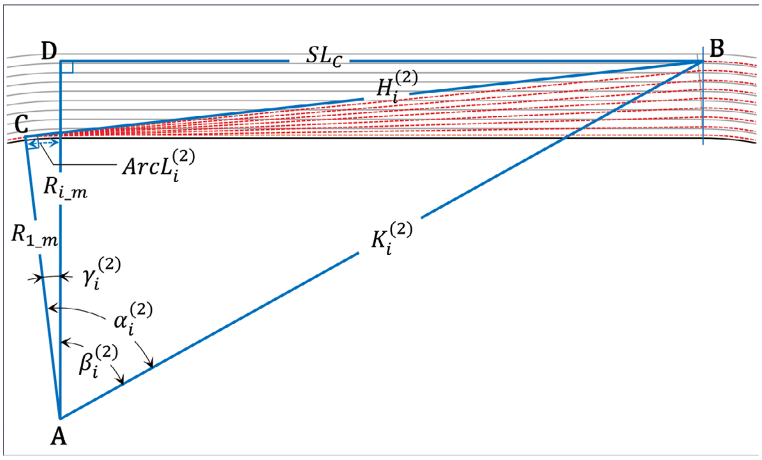


Figure 4. Calculation of reduction distance (RD_i).
RD_i is defined as the distance from $H_i^{(2)}$ minus SL_C and $ArcL_i^{(2)}$. **A** is the center of the second curve semicircle. **B** is the end of the measurement line of lane i in the first curve. **C** is the tangent point of the running line from **B**. **D** is the end of the measurement line of lane i in the back straight. SL_C denotes the length of the straight section (equals **BD**). $K_i^{(2)}$ represents the length of the diagonal line from **A** to **B**. $ArcL_i^{(2)}$ expresses the arc length on the curved measurement line in lane 1 overtaken by the tangent hypotenuse running line. $H_i^{(2)}$ stands for the length of the tangent hypotenuse running line for lane i (equals **BC**). R_{1_m} and R_{i_m}, respectively equal to **AC** and **AD**, represent the radii of the curved measurement line for lane i. $\alpha_i^{(2)}$ expresses the angle formed by lines **AB** and **AC**. $\beta_i^{(2)}$ denotes the angle formed by lines **AB** and **AD**. $\gamma_i^{(2)}$ represents the angle formed by lines **AC** and **AD**. i stands for lane number ($i \geq 1$). This figure shows the case of $i = 9$.

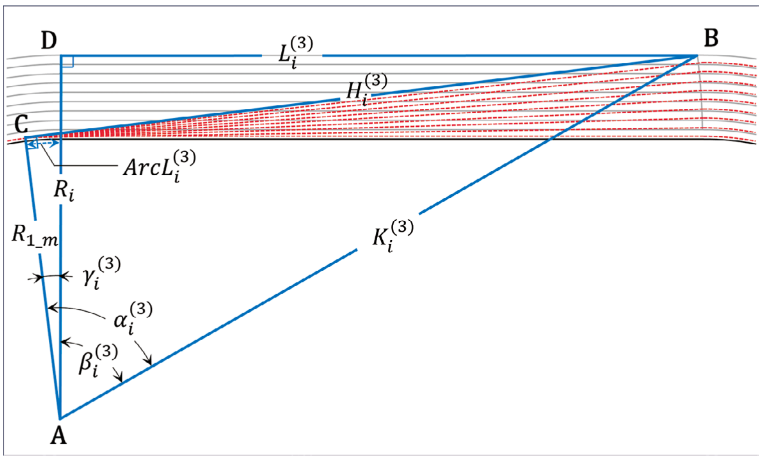


Figure 5. Calculation of the coordinates of the intersection of the break line and each lane line edge.
The distance from the intersection to the end of the back straight section ($L_i^{(3)}$) must be determined for this calculation. **A** is the center of the second curve semicircle. **B** is the intersection of the break line and the lane line edge in lane i, which can be either on the outer edge of the inside lane line or on the inner edge of the outside lane line. **C** is the tangent point of the running line from **B**. **D** is the end of the lane line edge of lane i in the back straight. $L_i^{(3)}$ denotes the length from **B** to **D**. $K_i^{(3)}$ represents the length of the diagonal line from **A** to **B**. $ArcL_i^{(3)}$ expresses the arc length on the curved measurement line in lane 1 overtaken by the tangent hypotenuse running line. $H_i^{(3)}$ stands for the length of the tangent hypotenuse running line from **B** (equals **BC**), which is expected to coincide with $ArcL_i^{(3)}$ plus the length of the straight section (SL_C). R_{1_m} represents the radius of the curved measurement line for lane 1 (equals **AC**). R_i stands for the radius of the curved lane line edge for lane i (equals **AC**). $\alpha_i^{(3)}$ expresses the angle formed by lines **AB** and **AC**. $\beta_i^{(3)}$ denotes the angle formed by lines **AB** and **AD**. $\gamma_i^{(3)}$ represents the angle formed by lines **AC** and **AD**. i stands for the lane number ($i \geq 1$). This figure shows the case of $i = 9$, the inner edge of the outside lane line.

$$H_i^{(3)} = ArcL_i^{(3)} + SL_C \quad (28)$$

The second description is the following.

$$H_i^{(3)} = \sqrt{K_i^{(3)2} - R_{1\_m}^{\ 2}} \quad (29)$$

In those equations, $K_i^{(3)}$, $\alpha_i^{(3)}$, $\beta_i^{(3)}$, $\gamma_i^{(3)}$, $ArcL_i^{(3)}$, and $H_i^{(3)}$ represent the lengths and angles defined in Figure 5. Equations (28) and (29) are expected to be equal. Solving them collectively yields determination of $L_i^{(3)}$. Because its closed form solution is difficult to obtain, an exploratory approach would be practical for solving it. Once $L_i^{(3)}$ is obtained, the coordinates can be found as presented below.

$$P_{i\_x} = -R_C - R_i \quad (30)$$

$$P_{i\_y} = -SL_C + L_i^{(3)} \quad (31)$$

i . The coordinates of the intersection of the arced start line for open-lane group starting in a 10000 m race and each lane line edge are calculable as shown below (R-h, Figure 6).

$$ArcL_i^{(4)} = H_i^{(4)} = \sqrt{R_i^{\ 2} - R_{1\_m}^{\ 2}} \quad (32)$$

$$\gamma_i^{(4)} = \frac{ArcL_i^{(4)}}{R_{1\_m}} \quad (33)$$

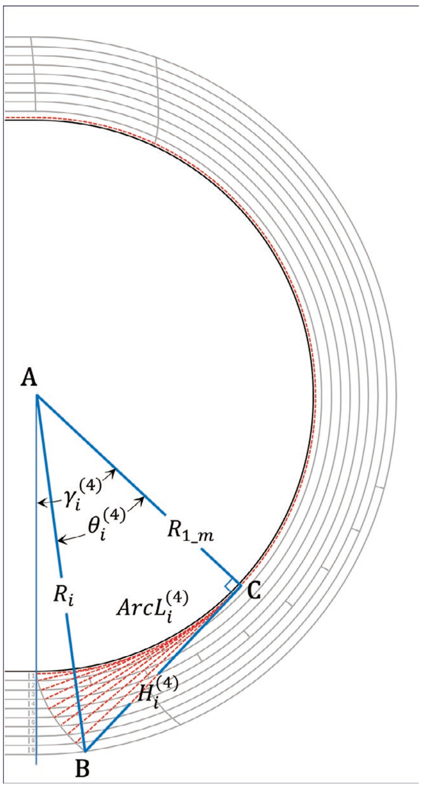


Figure 6. Calculation of the coordinates of the intersection of the start lines of 10000 m and each lane line edge. The start line of 5000 m is point symmetrical to this start line so that the common parameter values in the coordinate calculations can be applied for it. **A** is the center of the first curve semicircle. **B** is the intersection of the start line and the lane line edge in lane i, which can be either on the outer edge of the inside lane line or on the inner edge of the outside lane line. **C** is the tangent point of the running line from **B**. $ArcL_i^{(4)}$ denotes the arc length on the curved measurement line in lane 1 overtaken by the tangent hypotenuse running line. $H_i^{(4)}$ represents the length of the tangent running line from **B** (equals **BC**), which is expected to coincide with $ArcL_i^{(4)}$. R_{1_m} stands for the radius of the curved measurement line for lane 1 (equals **AC**). R_i signifies the radius of the curved lane line edge for lane i (equals **AC**). $\gamma_i^{(4)}$ denotes the angle formed by line **AC** and the end line of the straight section. $\theta_i^{(4)}$ expresses the angle formed by lines **AB** and **AC**. i stands for lane number ($i \geq 1$). This figure shows the case of $i = 9$, the inner edge of the outside lane line.

$$\theta_i^{(4)} = \cos^{-1}\left(\frac{R_{1\_m}}{R_i}\right) \quad (34)$$

$$P_{i\_x} = -R_C + R_i * \cos\left(\gamma_i^{(4)} - \theta_i^{(4)}\right) \quad (35)$$

$$P_{i\_y} = R_i * \sin\left(\gamma_i^{(4)} - \theta_i^{(4)}\right) \quad (36)$$

In those equations, $ArcL_i^{(4)}$, $H_i^{(4)}$, $\gamma_i^{(4)}$, and $\theta_i^{(4)}$ represent the lengths and angles defined in Figure 6. Those on the arced start line for a 5000 m race can be calculated similarly using the parameter values presented above.

$$P_{i\_x} = -R_C - R_i * \cos\left(\gamma_i^{(4)} - \theta_i^{(4)}\right) \quad (37)$$

$$P_{i\_y} = -SL_C - R_i * \sin\left(\gamma_i^{(4)} - \theta_i^{(4)}\right) \quad (38)$$

j. When more than 12 athletes participate in a 10000 m race, the separate arced start line on outer lanes (from lane 5 to lane 8 or 9) might be used (*R-j*). The athletes using the outer start line run in lane 5. They are permitted to join the athletes using the regular start line at the breakpoint. If the inside line of the outer group is marked with cones or

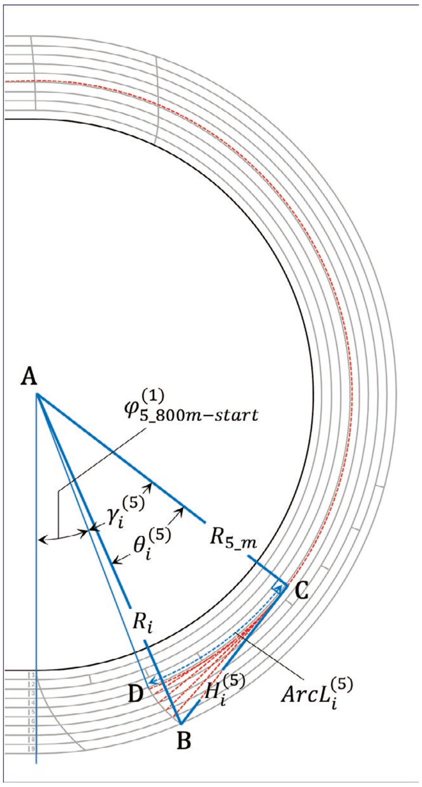


Figure 7. Calculation of the coordinates of the intersection of the separate arced start line of 10000 m on outer lanes and each lane line edge.
The outer start line of 5000 m is point symmetrical to this start line so that the common parameter values in the coordinate calculations can be applied for it. **A** is the center of the first curve semicircle. **B** is the intersection of the start line and the lane line edge in lane *i*, which can be either on the outer edge of the inside lane line or on the inner edge of the outside lane line. **C** is the tangent point of the running line from **B**. **D** is the root of the separate arced start line, which coincides with the intersection of the 800 m start line and the outer edge of the inside lane line in lane 5. $ArcL_i^{(5)}$ denotes the arc length on the curved measurement line in lane 1 overtaken by the tangent hypotenuse running line. $H_i^{(5)}$ represents the length of the tangent running line from **B** (equals **BC**), which is expected to coincide with $ArcL_i^{(5)}$. R_{5_m} stands for the radius of the curved measurement line for lane 5 (equals **AC**). R_i signifies the radius of the curved lane line edge for lane i (equals **AC**). $\gamma_i^{(5)}$ denotes the angle formed by lines **AC** and **AD**. $\theta_i^{(5)}$ expresses the angle formed by lines **AB** and **AC**. Here, $\varphi^{(1)}_{5\_800m-start}$ denotes the angle formed by line **AD** and the entrance line of the curve section. i stands for the lane number ($i \geq 5$). This figure shows the case of $i = 9$, the inner edge of the outside lane line.

flags, the inside root of outer arced start line coincides with the 800 m start line. The coordinates of the intersection of this start line and each lane line edge are calculable as follows (Figure 7).

$$ArcL_i^{(5)}=H_i^{(5)}=\sqrt{R_i^{2}-R_{5\_m}^{2}} \quad (39)$$

$$\gamma_i^{(5)}=\frac{ArcL_i^{(5)}}{R_{5\_m}} \quad (40)$$

$$\theta_i^{(5)}=\cos^{-1}\left(\frac{R_{5\_m}}{R_i}\right) \quad (41)$$

$$P_{i\_x}=-R_C+R_i*\cos(\varphi_{5\_800m-start}^{(1)}+\gamma_i^{(5)}-\theta_i^{(5)}) \quad (42)$$

$$P_{i\_y}=R_i*\sin(\varphi_{5\_800m-start}^{(1)}+\gamma_i^{(5)}-\theta_i^{(5)}) \quad (43)$$

In those equations, $ArcL_i^{(5)}$, $H_i^{(5)}$, $\gamma_i^{(5)}$, and $\theta_i^{(5)}$ represent the lengths and angles defined in Figure 7. The value of $\varphi_{5\_800m-start}^{(1)}$ represents the angle between the finish line and the 800 m start line in lane 5 which can be obtained with the equation (7). If the inside line of the outer group is marked with a temporary kerb, then R_{5_m} and $\varphi_{5\_800m-start}^{(1)}$ above are expected to be replaced respectively by the corrected values (R'_{5_m} and $\varphi_{5\_outer-start\_kerb}^{(5)}$). Also, R'_{5_m} is calculable using equation (3), by substituting 5 for i and by replacing 0.200 with 0.300. The values of 0.200 and 0.300 are the distances between the inside line and the measurement line, and 0.300 must be used with a temporary kerb (R-e, R-j). By applying R'_{5_m} into equations (16)–(22), the corrected value of RD_5 can be obtained as RD'_5. This value enables the calculation of the corresponding distance back from the end of section to the root of the start line in lane 5 ($D'_{5\_outer-start\_kerb}$), and subsequently enables the calculation of $\varphi_{5\_outer-start\_kerb}^{(5)}$. Thereafter, the coordinates of the 10000 m outer start line can be calculated usint equations (39)–(43). For 5000 m races, a separated arced start line might also be used. Its coordinates are calculable using the same parameter values as those presented above.

$$P_{i\_x}=-R_C-R_i*\cos(\varphi_{5\_800m-start}^{(1)}+\gamma_i^{(5)}-\theta_i^{(5)}) \quad (44)$$

$$P_{i\_y}=-SL_C-R_i*\sin(\varphi_{5\_800m-start}^{(1)}+\gamma_i^{(5)}-\theta_i^{(5)}) \quad (45)$$

For these equations, the arguments of trigonometric functions should be replaced by the corrected values if the inside line is marked with a temporary kerb. The inside root of this outer start line is located forward of the 200 m start line by the reduction distance in lane 5 (RD_5 or RD'_5). The breakpoint is located at the end of the second curve on the inside line of lane 5, which is slightly different from that on the break line located ahead of the end of the first curve (R-j, Figure 8). The coordinates of this breakpoint on the outer edge of the inside lane line in lane 5 can be expressed with the radius of this edge (R_{5_in}).

$$P_{5\_in\_x}=-R_C+R_{5\_in} \quad (46)$$

$$P_{5\_in\_y}=-SL_C \quad (47)$$

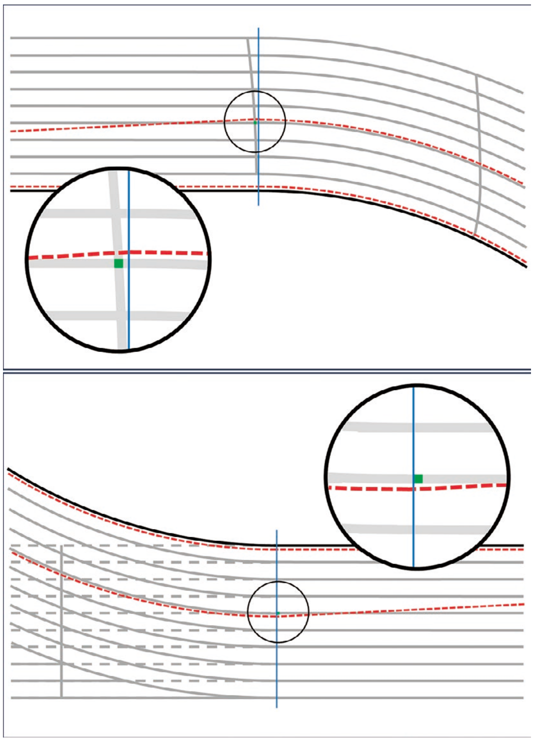


Figure 8. Difference in the position of breakpoints between that on the break line immediately after the entrance of the back straight section (top) and that at the entrance of the home straight section (bottom).
The breakpoint on the break line is somewhat distant from the entrance of the back straight section, whereas that on the home straight section is located just at the entrance of the section.

k. The start line of 1500 m is a combination of two arcs based on different tangent lines: The inner part is defined by the tangent line of the first curve, whereas the outer part is defined by that of the second curve. The calculation of their coordinates differs between the inner and outer parts. Therefore, it is necessary to ascertain first whether a lane line edge of interest intersects with the inner or outer part of the start line. This can be accomplished by referring to the distance between the switch point and the center of first curve (R_S, Figure 9), which is calculable as presented below.

$$H_S = 100.000 - SL_C \tag{48}$$

$$R_S = \sqrt{H_S{}^2 + R_{1\_m}{}^2} \tag{49}$$

In those equations, 100.000 is the distance from the end of the back straight section to the start line of the 1500 m. Also, H_S denotes the length between that start line and the entrance of the back straight section. Lane line edges with a radius smaller than R_S intersect with the inner part of the start line, whereas those with a larger radius intersect with the outer part.

l. The coordinates of the intersection between the inner portion of the start line for 1500 m and the edge of each lane line are calculable as explained hereinafter (Figure 10).

$$ArcL_i^{(6)} = H_i^{(6)} = \sqrt{R_i{}^2 - R_{1\_m}{}^2} \tag{50}$$

$$\theta_i^{(6)} = cos^{-1}\left(\frac{R_{1\_m}}{R_i}\right) \tag{51}$$

$$D_{1\_1500m-start} = H_S = 100.000 - SL_C \tag{52}$$

$$\gamma_i^{(6)} = \frac{D_{1\_1500m-start} - ArcL_i^{(6)}}{R_{1\_m}} \tag{53}$$

$$P_{i\_x} = -R_C - R_i * \cos\left(\gamma_i^{(6)} + \theta_i^{(6)}\right) \tag{54}$$

$$P_{i\_y} = R_i * \sin\left(\gamma_i^{(6)} + \theta_i^{(6)}\right) \tag{55}$$

In those equations, $ArcL_i^{(6)}$, $H_i^{(6)}$, $\theta_i^{(6)}$, and $\gamma_i^{(6)}$ represent the lengths and angles defined in Figure 10. The value of $D_{1\_1500m-start}$ represents the arc length on the curved measurement line in lane 1, which is expected to coincide to H_S in equation (48).

m. The coordinates of the intersection of the outer portion of the start line for 1500 m and the edge of each lane line are obtainable by calculating $\theta_i^{(7)}$ as defined in Figure 11. With a given $\theta_i^{(7)}$, the length of the tangent hypotenuse running line from the intersection of the break line and the lane line edge ($H_i^{(7)}$) can be determined in two ways. The first is the following (Figure 11).

$$L_i^{(7)} = SL_C + R_i * \sin\theta_i^{(7)} \tag{56}$$

Figure 9. Location of the switch point of the inner and outer parts of the arced start line of 1500 m.
A is the center of the first curve semicircle. **B** is the switch point. **C** is the end of the curved measurement line of lane 1 in the first curve. H_s denotes the length from **B** to **C**. R_{1_m} stands for the radius of the curved measurement line for lane 1 (equals **AC**). R_S represents the distance between **A** and **B**. The distance between **B** and the end of the back straight is 100 m.

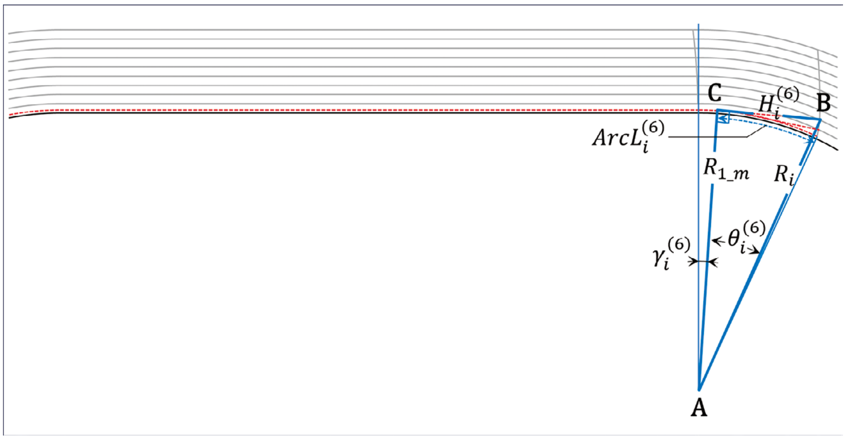


Figure 10. Calculation of the coordinates of the intersection between the inner portion of the start line for 1500 m and the edge of each lane line.
A is the center of the first curve semicircle. **B** is the intersection between the start line and the edge of lane line in lane i, which can be either on the outer edge of the inside lane line or on the inner edge of the outside lane line. **C** is the tangent point of the running line from **B**. $ArcL_i^{(6)}$ denotes the arc length on the curved measurement line in lane 1 overtaken by the tangent hypotenuse running line. $H_i^{(6)}$ represents the length of the tangent running line from **B** (equals **BC**), which is expected to coincide to $ArcL_i^{(6)}$. R_{1_m} represents the radius of the curved measurement line for lane 1 (equals **AC**). R_i stands for the radius of the curved lane line edge for lane i (equals **AB**). $\theta_i^{(6)}$ denotes the angle formed by lines **AB** and **AC**. $\gamma_i^{(6)}$ expresses the angle formed by line **AC** and the end line of the first curve section. i stands for the lane number ($i \geq 1$). This figure shows the case of $i = 2$, the inner edge of the outside lane line.

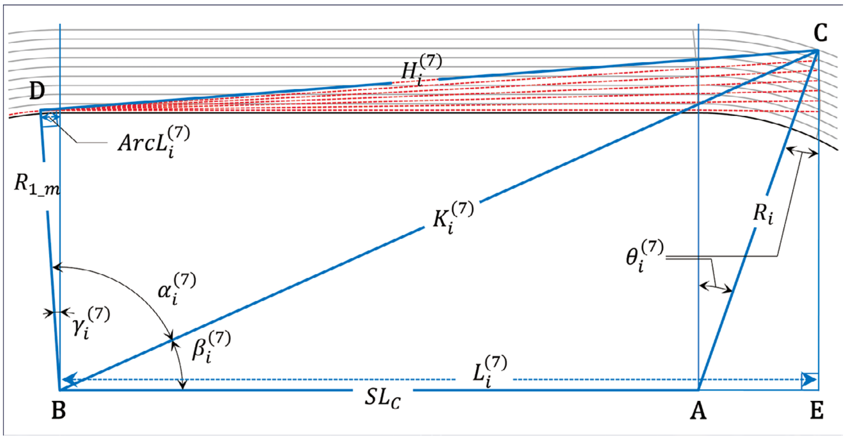


Figure 11. Calculation of the coordinates of the intersection between the outer portion of the start line for 1500 m and the edge of each lane line.
A is the center of the first curve semicircle. **B** is the center of the second curve semicircle. **C** is the intersection between the start line and the edge of lane line in lane i, which can be either on the outer edge of the inside lane line or on the inner edge of the outside lane line. **D** is the tangent point of the running line from **C**. **E** is the intersection of the extension of **AB** and a perpendicular line drawn from **C** to this extension line. $ArcL_i^{(7)}$ expresses the arc length on the curved measurement line in lane 1 overtaken by the tangent hypotenuse running line. $H_i^{(7)}$ stands for the length of the tangent hypotenuse running line from **C** (equals **CD**), which is expected to coincide with $ArcL_i^{(7)}$ plus 100 m. R_{1_m} stands for the radius of the curved measurement line for lane 1 (equals **BD**). R_i expresses the radius of the curved lane line edge for lane i (equals **AC**). $K_i^{(7)}$ and $L_i^{(7)}$ respectively represent the lengths from **B** to **C** and from **B** to **E**. $\alpha_i^{(7)}$ signifies the angle formed by lines **BC** and **BD**. $\beta_i^{(7)}$ expresses the angle formed by lines **BC** and **BE**. $\gamma_i^{(7)}$ represents the angle formed by lines **BD** and the end line of the back straight section. $\theta_i^{(7)}$ denotes the angle formed by line **AC** and the end line of the first curve section, which equals the angle formed by lines **AC** and **CE**. i stands for the lane number ($i \geq 1$). This figure shows the case of $i = 9$, the inner edge of the outside lane line.

$$K_i^{(7)}=\sqrt{L_i^{(7)2}+(R_i*\cos\theta_i^{(7)})^2} \qquad (57)$$

$$\alpha_i^{(7)}=\cos^{-1}\left(\frac{R_{1\_m}}{K_i^{(7)}}\right)\quad [0<\alpha_i^{(7)}<\pi/2] \qquad (58)$$

$$\beta_i^{(7)}=\tan^{-1}\left(\frac{R_i*\cos\theta_i^{(7)}}{L_i^{(7)}}\right)\quad [0<\beta_i^{(7)}<\pi/2] \qquad (59)$$

$$\gamma_i^{(7)}=\alpha_i^{(7)}+\beta_i^{(7)}-\pi/2 \qquad (60)$$

$$ArcL_i^{(7)}=R_{1\_m}*\gamma_i^{(7)} \qquad (61)$$

$$H_i^{(7)}=ArcL_i^{(7)}+100.000 \qquad (62)$$

In those equations, $L_i^{(7)}$, $K_i^{(7)}$, $\alpha_i^{(7)}$, $\beta_i^{(7)}$, $\gamma_i^{(7)}$, and $ArcL_i^{(7)}$ represent the lengths and angles defined in Figure 11. Also, 100.000 is the distance from the end of the back straight section to the start line of the 1500 m. The second is the following.

$$H_i^{(7)}=\sqrt{K_i^{(7)2}-R_{1\_m}{}^2} \qquad (63)$$

These equations are expected to be equal. Solving them collectively yields determination of $\theta_i^{(7)}$. An exploratory approach might be practical for solving it. Once $\theta_i^{(7)}$ is obtained, the coordinates can be found as presented below.

$$P_{i\_x}=-R_C-R_i*\cos\theta_i^{(7)} \qquad (64)$$

$$P_{i\_y}=R_i*\sin\theta_i^{(7)} \qquad (65)$$

To ascertain the usability of the coordinate calculation method above, tracks of two typical layouts, i.e., those with straight length of 84.39 m (i.e., WA standard track, used in most recent international competitions) and 80.00 m (commonly used for most tracks in Japan), were selected to calculate their mark coordinates. Solver (an add-in program for Microsoft Excel, Microsoft Office Professional 2016, Microsoft Corp., USA) was used to obtain exploratory solutions of the coordinates related to the break line and the 1500 m start line.

3. Identification of the analysis-point positions and examination of its accuracy

Once the track mark coordinates are obtained, the positions of the analysis points can be identified. In the image captured in the vicinity of the analysis point, some recognizable marks must be identified as reference marks. Then their positions on the image coordinates must be determined. By combining the image coordinates with the corresponding track coordinates calculated above, matrices of the coordinate transformation homography can be calculated. The track coordinates of the analysis point can be calculated using the same methods as those used for the reference marks. Then they can be transformed to image coordinates using the inverse matrix of the homography. Finally, the analysis points can be projected and visualized on the image.

We demonstrated this analysis-point position identification using two examples of race analysis. One example is to obtain the 100 m split time in an athletics 800 m race. In this race, the runner starts from the echelon start line and runs in a separate lane within the first curve section. The 100 m point is located on this first curve, before the break line. No mark designates this 100 m point position. To identify this point, the reduction distance must be considered, similarly to a case of the start line of 800 m. The other example is to obtain the 100 m, 200 m, and 300 m split times of the first leg in a 4×400 m relay race. The first-leg runner starts from the largely separated echelon start line, and runs a lap of track along the designated lane. The 100 m, 200 m, and 300 m points are located respectively around the second, third, and fourth corner of the track. No mark signifies these positions. To identify them, the reduction distance and the difference in the running line lap distance between lanes must be considered.

On a standard track stadium, the areas around the analysis points were photographed from the spectators' stand. With recognizable marks on these images, the coordinate transformation homography matrices were calculated. The coordinates for the outer start line of 5000 m with a temporary kerb were used for the matrix calculation with the image around the 200 m point of the first leg in a 4×400 m relay race. The image coordinates of the analysis points were obtained with the inverse matrices. Thereafter, the analysis-point positions were identified by projecting their image coordinates onto the photographed images. Both inside and outside positions were determined, allowing each analysis point to be represented as a line connecting these positions. A custom-made Python program using a computer vision library（OpenCV-python 4.7.0.72）was used for these processes, i.e., identifying reference marks, obtaining their image coordinates, performing matrix calculations, and conducting analysis-point projections.

To ascertain the reliability of this analysis-point identification method, the accuracy of the identified position was evaluated. Because it is difficult to ascertain the true position of the analysis points on the track, the reference track marks were used as the subject for examination instead. Applying the concept of leave-one-out cross-validation（LOOCV）to this examination, each mark was used as a single test point, whereas the remaining marks were used as references for calculating the homography matrix for identifying the position of the test point. The identification error was evaluated with the Euclidean distance of the track coordinates between the identified position and its true position, as determined from the photographed image. For each photographed image, the average and standard deviation of the distance were calculated for all the track mark points.

Ⅲ. Results

1. Mark coordinates for typical tracks

Tables 2 and 3 present the results of coordinate calculation conducted for two typical tracks. Illustrations of the tracks rendered according to the results are also portrayed in Figures 12 and 13.

2. Identified analysis points for example race analyses

The track coordinates of the analysis points for 800 m and 4×400 m relay races are also presented in Tables 2 and 3. Figure 14 exhibits images of the area around the analysis points, with the reference track mark positions and identified analysis points highlighted.

3. Accuracy of analysis-point position identification

The accuracy evaluated using the LOOCV method is presented in Table 4. In all analyzed images, the error distance between the identified and the true positions was approximately 0.040 m, on average.

Ⅳ. Discussion

This study assessed a method for calculating the coordinates of marks on athletics tracks comprehensively and demonstrated coordinate calculations for typical tracks. Because these calculations necessitate considerably intensive effort, our demonstration results are expected to be valuable for future analyses associated with these typical tracks. One such track, WA standard track, is used for most international competitions, including world athletics championships. The other, the 80-m straight track, is commonly found on the majority of Japanese tracks. Consequently, our coordinate calculation results could be utilized to analyze most international and Japanese domestic competitions. Furthermore, this study provided two practical use examples of the current coordinate calculation results for race analysis. While no mark exists for the analysis points, the current method accommodated identification of their positions, and would enable us to perform detailed race analyses.

When using the methods applied for this study, the track layout must be known first. The most important element of the track layout is the length of the straight（SL_C）. In addition to direct measurement, another means of ascertaining SL_C is to check the position of the inner edge of the 100 m or 110 m hurdle start line on the second curve. If the SL_C is 84.39 m（i.e., WA standard track）, then the edge of the 100 m start line should be located within lane 3, slightly outside the centerline of the lane. The edge of 110 m hurdle start

Table 2. Coordinates of marks of the World Athletics standard track.

Mark	Lane 1		Lane 2		Lane 3		Lane 4		Lane 5		Lane 6		Lane 7		Lane 8		Lane 9	
	inside	outside	inside	outside	inside	outside	inside	outside	inside	outside	inside	outside	inside	outside	inside	outside	inside	outside
Finish Line	[0.000, 0.000]	[1.170, 0.000]	[1.220, 0.000]	[2.390, 0.000]	[2.440, 0.000]	[3.610, 0.000]	[3.660, 0.000]	[4.830, 0.000]	[4.880, 0.000]	[6.050, 0.000]	[6.100, 0.000]	[7.270, 0.000]	[7.320, 0.000]	[8.490, 0.000]	[8.540, 0.000]	[9.710, 0.000]	[9.760, 0.000]	[10.930, 0.000]
Start Line																		
100m / 100mH	[0.000, -100.000]	[1.170, -100.000]	[1.220, -100.000]	[2.390, -100.000]	[2.440, -100.000]	[3.610, -100.000]	[3.660, -100.000]	[4.830, -100.000]	[4.880, -100.000]	[6.050, -100.000]	[6.100, -100.000]	[7.270, -100.000]	[7.320, -100.000]	[8.490, -100.000]	[8.540, -100.000]	[9.710, -100.000]	[9.760, -100.000]	[10.930, -100.000]
110mH	[0.000, -110.000]	[1.170, -110.000]	[1.220, -110.000]	[2.390, -110.000]	[2.440, -110.000]	[3.610, -110.000]	[3.660, -110.000]	[4.830, -110.000]	[4.880, -110.000]	[6.050, -110.000]	[6.100, -110.000]	[7.270, -110.000]	[7.320, -110.000]	[8.490, -110.000]	[8.540, -110.000]	[9.710, -110.000]	[9.760, -110.000]	[10.930, -110.000]
200m	[-73.000, -84.390]	[-74.170, -84.390]	[-74.057, -87.885]	[-75.222, -87.993]	[-74.755, -91.661]	[-75.904, -91.879]	[-75.128, -95.377]	[-76.253, -95.697]	[-75.210, -99.012]	[-76.305, -99.425]	[-75.035, -102.551]	[-76.093, -103.050]	[-74.630, -105.983]	[-75.648, -106.560]	[-74.023, -109.302]	[-74.997, -109.949]	[-73.237, -112.504]	[-74.166, -113.215]
400m / 4x100mR	[0.000, 0.000]	[1.170, 0.000]	[0.572, 6.960]	[1.722, 7.176]	[-0.275, 14.286]	[0.813, 14.715]	[-2.351, 21.135]	[-1.357, 21.751]	[-5.453, 27.357]	[-4.576, 28.131]	[-9.384, 32.856]	[-8.640, 33.758]	[-13.961, 37.579]	[-13.359, 38.582]	[-19.019, 41.509]	[-18.565, 42.587]	[-24.411, 44.652]	[-24.106, 45.782]
800m	[0.000, 0.000]	[1.170, 0.000]	[1.057, 3.502]	[2.222, 3.611]	[1.749, 7.302]	[2.898, 7.522]	[2.108, 11.058]	[3.232, 11.380]	[2.163, 14.747]	[3.256, 15.164]	[1.945, 18.350]	[3.001, 18.854]	[1.480, 21.857]	[2.494, 22.440]	[0.793, 25.255]	[1.762, 25.912]	[-0.094, 28.541]	[0.827, 29.262]
4x400mR	[0.000, 0.000]	[1.170, 0.000]	[-0.234, 10.372]	[0.891, 10.694]	[-3.597, 20.826]	[-2.608, 21.451]	[-9.491, 29.721]	[-8.704, 30.587]	[-17.241, 36.625]	[-16.697, 37.661]	[-26.182, 41.331]	[-25.899, 42.467]	[-35.709, 43.813]	[-35.688, 44.982]	[-45.301, 44.171]	[-45.530, 45.319]	[-54.535, 42.599]	[-54.991, 43.677]
1500m	[-70.038, 15.146]	[-70.883, 15.388]	[-70.934, 15.398]	[-72.139, 15.564]	[-72.192, 15.568]	[-73.447, 15.610]	[-73.502, 15.610]	[-74.773, 15.599]	[-74.827, 15.598]	[-76.098, 15.571]	[-76.152, 15.569]	[-77.424, 15.525]	[-77.478, 15.523]	[-78.749, 15.462]	[-78.803, 15.459]	[-80.074, 15.382]	[-80.129, 15.378]	[-81.399, 15.285]
5000m	[-73.000, -84.390]	[-74.169, -84.518]	[-74.219, -84.529]	[-75.387, -84.874]	[-75.436, -84.892]	[-76.598, -85.371]	[-76.647, -85.394]	[-77.799, -85.986]	[-77.848, -86.014]	[-78.986, -86.709]	[-79.035, -86.741]	[-80.157, -87.532]	[-80.204, -87.568]	[-81.306, -88.450]	[-81.353, -88.490]	[-82.431, -89.460]	[-82.476, -89.503]	[-83.527, -90.559]
5000m outer group									[-75.163, -99.137]	[-76.205, -99.686]	[-76.248, -99.714]	[-77.220, -100.443]	[-77.260, -100.477]	[-78.184, -101.318]	[-78.222, -101.356]	[-79.102, -102.291]	[-79.138, -102.332]	[-79.975, -103.351]
5000m outer group with temporal kerb									[-75.062, -99.399]	[-76.108, -99.935]	[-76.151, -99.963]	[-77.122, -100.688]	[-77.163, -100.721]	[-78.084, -101.560]	[-78.123, -101.598]	[-79.000, -102.531]	[-79.037, -102.572]	[-79.870, -103.589]
10000m	[0.000, 0.000]	[1.170, 0.128]	[1.220, 0.139]	[2.387, 0.484]	[2.437, 0.502]	[3.598, 0.981]	[3.647, 1.004]	[4.799, 1.596]	[4.848, 1.624]	[5.987, 2.319]	[6.035, 2.351]	[7.157, 3.142]	[7.205, 3.178]	[8.306, 4.060]	[8.353, 4.100]	[9.431, 5.070]	[9.477, 5.113]	[10.527, 6.169]
10000m outer group									[2.163, 14.747]	[3.206, 15.296]	[3.248, 15.324]	[4.220, 16.053]	[4.260, 16.087]	[5.184, 16.928]	[5.222, 16.966]	[6.102, 17.901]	[6.139, 17.942]	[6.975, 18.961]
5000m outer group with temporal kerb									[2.062, 15.009]	[3.109, 15.545]	[3.151, 15.573]	[4.123, 16.298]	[4.163, 16.331]	[5.085, 17.170]	[5.123, 17.208]	[6.000, 18.141]	[6.037, 18.182]	[6.870, 19.199]
Break Line			[-74.220, -0.005]	[-75.390, -0.026]	[-75.440, -0.027]	[-76.610, -0.065]	[-76.660, -0.067]	[-77.830, -0.121]	[-77.880, -0.123]	[-79.050, -0.194]	[-79.100, -0.198]	[-80.270, -0.285]	[-80.320, -0.289]	[-81.490, -0.393]	[-81.540, -0.398]	[-82.710, -0.518]	[-82.760, -0.524]	[-83.930, -0.660]
Break Point								[4.830, -84.390]	[4.880, -84.390]									
Hurdle																		
100mH 1st	[0.000, -87.000]	[1.170, -87.000]	[1.220, -87.000]	[2.390, -87.000]	[2.440, -87.000]	[3.610, -87.000]	[3.660, -87.000]	[4.830, -87.000]	[4.880, -87.000]	[6.050, -87.000]	[6.100, -87.000]	[7.270, -87.000]	[7.320, -87.000]	[8.490, -87.000]	[8.540, -87.000]	[9.710, -87.000]	[9.760, -87.000]	[10.930, -87.000]
100mH 2st	[0.000, -78.500]	[1.170, -78.500]	[1.220, -78.500]	[2.390, -78.500]	[2.440, -78.500]	[3.610, -78.500]	[3.660, -78.500]	[4.830, -78.500]	[4.880, -78.500]	[6.050, -78.500]	[6.100, -78.500]	[7.270, -78.500]	[7.320, -78.500]	[8.490, -78.500]	[8.540, -78.500]	[9.710, -78.500]	[9.760, -78.500]	[10.930, -78.500]
100mH 3st	[0.000, -70.000]	[1.170, -70.000]	[1.220, -70.000]	[2.390, -70.000]	[2.440, -70.000]	[3.610, -70.000]	[3.660, -70.000]	[4.830, -70.000]	[4.880, -70.000]	[6.050, -70.000]	[6.100, -70.000]	[7.270, -70.000]	[7.320, -70.000]	[8.490, -70.000]	[8.540, -70.000]	[9.710, -70.000]	[9.760, -70.000]	[10.930, -70.000]
100mH 4st	[0.000, -61.500]	[1.170, -61.500]	[1.220, -61.500]	[2.390, -61.500]	[2.440, -61.500]	[3.610, -61.500]	[3.660, -61.500]	[4.830, -61.500]	[4.880, -61.500]	[6.050, -61.500]	[6.100, -61.500]	[7.270, -61.500]	[7.320, -61.500]	[8.490, -61.500]	[8.540, -61.500]	[9.710, -61.500]	[9.760, -61.500]	[10.930, -61.500]
100mH 5st	[0.000, -53.000]	[1.170, -53.000]	[1.220, -53.000]	[2.390, -53.000]	[2.440, -53.000]	[3.610, -53.000]	[3.660, -53.000]	[4.830, -53.000]	[4.880, -53.000]	[6.050, -53.000]	[6.100, -53.000]	[7.270, -53.000]	[7.320, -53.000]	[8.490, -53.000]	[8.540, -53.000]	[9.710, -53.000]	[9.760, -53.000]	[10.930, -53.000]
100mH 6st	[0.000, -44.500]	[1.170, -44.500]	[1.220, -44.500]	[2.390, -44.500]	[2.440, -44.500]	[3.610, -44.500]	[3.660, -44.500]	[4.830, -44.500]	[4.880, -44.500]	[6.050, -44.500]	[6.100, -44.500]	[7.270, -44.500]	[7.320, -44.500]	[8.490, -44.500]	[8.540, -44.500]	[9.710, -44.500]	[9.760, -44.500]	[10.930, -44.500]
100mH 7st	[0.000, -36.000]	[1.170, -36.000]	[1.220, -36.000]	[2.390, -36.000]	[2.440, -36.000]	[3.610, -36.000]	[3.660, -36.000]	[4.830, -36.000]	[4.880, -36.000]	[6.050, -36.000]	[6.100, -36.000]	[7.270, -36.000]	[7.320, -36.000]	[8.490, -36.000]	[8.540, -36.000]	[9.710, -36.000]	[9.760, -36.000]	[10.930, -36.000]
100mH 8st	[0.000, -27.500]	[1.170, -27.500]	[1.220, -27.500]	[2.390, -27.500]	[2.440, -27.500]	[3.610, -27.500]	[3.660, -27.500]	[4.830, -27.500]	[4.880, -27.500]	[6.050, -27.500]	[6.100, -27.500]	[7.270, -27.500]	[7.320, -27.500]	[8.490, -27.500]	[8.540, -27.500]	[9.710, -27.500]	[9.760, -27.500]	[10.930, -27.500]
100mH 9st	[0.000, -19.000]	[1.170, -19.000]	[1.220, -19.000]	[2.390, -19.000]	[2.440, -19.000]	[3.610, -19.000]	[3.660, -19.000]	[4.830, -19.000]	[4.880, -19.000]	[6.050, -19.000]	[6.100, -19.000]	[7.270, -19.000]	[7.320, -19.000]	[8.490, -19.000]	[8.540, -19.000]	[9.710, -19.000]	[9.760, -19.000]	[10.930, -19.000]
100mH 10st	[0.000, -10.500]	[1.170, -10.500]	[1.220, -10.500]	[2.390, -10.500]	[2.440, -10.500]	[3.610, -10.500]	[3.660, -10.500]	[4.830, -10.500]	[4.880, -10.500]	[6.050, -10.500]	[6.100, -10.500]	[7.270, -10.500]	[7.320, -10.500]	[8.490, -10.500]	[8.540, -10.500]	[9.710, -10.500]	[9.760, -10.500]	[10.930, -10.500]
110mH 1st	[0.000, -96.280]	[1.170, -96.280]	[1.220, -96.280]	[2.390, -96.280]	[2.440, -96.280]	[3.610, -96.280]	[3.660, -96.280]	[4.830, -96.280]	[4.880, -96.280]	[6.050, -96.280]	[6.100, -96.280]	[7.270, -96.280]	[7.320, -96.280]	[8.490, -96.280]	[8.540, -96.280]	[9.710, -96.280]	[9.760, -96.280]	[10.930, -96.280]
110mH 2st	[0.000, -87.140]	[1.170, -87.140]	[1.220, -87.140]	[2.390, -87.140]	[2.440, -87.140]	[3.610, -87.140]	[3.660, -87.140]	[4.830, -87.140]	[4.880, -87.140]	[6.050, -87.140]	[6.100, -87.140]	[7.270, -87.140]	[7.320, -87.140]	[8.490, -87.140]	[8.540, -87.140]	[9.710, -87.140]	[9.760, -87.140]	[10.930, -87.140]
110mH 3st	[0.000, -78.000]	[1.170, -78.000]	[1.220, -78.000]	[2.390, -78.000]	[2.440, -78.000]	[3.610, -78.000]	[3.660, -78.000]	[4.830, -78.000]	[4.880, -78.000]	[6.050, -78.000]	[6.100, -78.000]	[7.270, -78.000]	[7.320, -78.000]	[8.490, -78.000]	[8.540, -78.000]	[9.710, -78.000]	[9.760, -78.000]	[10.930, -78.000]
110mH 4st	[0.000, -68.860]	[1.170, -68.860]	[1.220, -68.860]	[2.390, -68.860]	[2.440, -68.860]	[3.610, -68.860]	[3.660, -68.860]	[4.830, -68.860]	[4.880, -68.860]	[6.050, -68.860]	[6.100, -68.860]	[7.270, -68.860]	[7.320, -68.860]	[8.490, -68.860]	[8.540, -68.860]	[9.710, -68.860]	[9.760, -68.860]	[10.930, -68.860]
110mH 5st	[0.000, -59.720]	[1.170, -59.720]	[1.220, -59.720]	[2.390, -59.720]	[2.440, -59.720]	[3.610, -59.720]	[3.660, -59.720]	[4.830, -59.720]	[4.880, -59.720]	[6.050, -59.720]	[6.100, -59.720]	[7.270, -59.720]	[7.320, -59.720]	[8.490, -59.720]	[8.540, -59.720]	[9.710, -59.720]	[9.760, -59.720]	[10.930, -59.720]
110mH 6st	[0.000, -50.580]	[1.170, -50.580]	[1.220, -50.580]	[2.390, -50.580]	[2.440, -50.580]	[3.610, -50.580]	[3.660, -50.580]	[4.830, -50.580]	[4.880, -50.580]	[6.050, -50.580]	[6.100, -50.580]	[7.270, -50.580]	[7.320, -50.580]	[8.490, -50.580]	[8.540, -50.580]	[9.710, -50.580]	[9.760, -50.580]	[10.930, -50.580]
110mH 7st	[0.000, -41.440]	[1.170, -41.440]	[1.220, -41.440]	[2.390, -41.440]	[2.440, -41.440]	[3.610, -41.440]	[3.660, -41.440]	[4.830, -41.440]	[4.880, -41.440]	[6.050, -41.440]	[6.100, -41.440]	[7.270, -41.440]	[7.320, -41.440]	[8.490, -41.440]	[8.540, -41.440]	[9.710, -41.440]	[9.760, -41.440]	[10.930, -41.440]
110mH 8st	[0.000, -32.300]	[1.170, -32.300]	[1.220, -32.300]	[2.390, -32.300]	[2.440, -32.300]	[3.610, -32.300]	[3.660, -32.300]	[4.830, -32.300]	[4.880, -32.300]	[6.050, -32.300]	[6.100, -32.300]	[7.270, -32.300]	[7.320, -32.300]	[8.490, -32.300]	[8.540, -32.300]	[9.710, -32.300]	[9.760, -32.300]	[10.930, -32.300]
110mH 9st	[0.000, -23.160]	[1.170, -23.160]	[1.220, -23.160]	[2.390, -23.160]	[2.440, -23.160]	[3.610, -23.160]	[3.660, -23.160]	[4.830, -23.160]	[4.880, -23.160]	[6.050, -23.160]	[6.100, -23.160]	[7.270, -23.160]	[7.320, -23.160]	[8.490, -23.160]	[8.540, -23.160]	[9.710, -23.160]	[9.760, -23.160]	[10.930, -23.160]
110mH 10st	[0.000, -14.020]	[1.170, -14.020]	[1.220, -14.020]	[2.390, -14.020]	[2.440, -14.020]	[3.610, -14.020]	[3.660, -14.020]	[4.830, -14.020]	[4.880, -14.020]	[6.050, -14.020]	[6.100, -14.020]	[7.270, -14.020]	[7.320, -14.020]	[8.490, -14.020]	[8.540, -14.020]	[9.710, -14.020]	[9.760, -14.020]	[10.930, -14.020]
400mH 1st	[-24.054, 34.312]	[-23.655, 35.412]	[-29.061, 36.979]	[-28.831, 38.126]	[-34.731, 38.900]	[-34.678, 40.068]	[-40.445, 39.966]	[-40.560, 41.130]	[-46.085, 40.254]	[-46.356, 41.392]	[-51.564, 39.847]	[-51.978, 40.942]	[-56.813, 38.827]	[-57.356, 39.864]	[-61.786, 37.272]	[-62.443, 38.240]	[-66.449, 35.256]	[-67.207, 36.148]
400mH 2nd	[-57.203, 30.060]	[-57.867, 31.024]	[-61.499, 28.246]	[-62.274, 29.122]	[-65.724, 25.735]	[-66.602, 26.508]	[-69.527, 22.848]	[-70.489, 23.514]	[-72.907, 19.667]	[-73.937, 20.223]	[-75.875, 16.259]	[-76.956, 16.706]	[-78.443, 12.685]	[-79.563, 13.023]	[-80.632, 8.994]	[-81.779, 9.228]	[-82.463, 5.228]	[-83.626, 5.361]
400mH 3rd	[-72.995, 0.605]	[-74.164, 0.624]	[-74.220, -2.909]	[-75.390, -2.909]	[-75.440, -6.741]	[-76.610, -6.741]	[-76.660, -10.574]	[-77.830, -10.574]	[-77.880, -14.407]	[-79.050, -14.407]	[-79.100, -18.240]	[-80.270, -18.240]	[-80.320, -22.072]	[-81.490, -22.072]	[-81.540, -25.905]	[-82.710, -25.905]	[-82.760, -29.738]	[-83.930, -29.738]
400mH 4th	[-73.000, -34.390]	[-74.170, -34.390]	[-74.220, -37.909]	[-75.390, -37.909]	[-75.440, -41.741]	[-76.610, -41.741]	[-76.660, -45.574]	[-77.830, -45.574]	[-77.880, -49.407]	[-79.050, -49.407]	[-79.100, -53.240]	[-80.270, -53.240]	[-80.320, -57.072]	[-81.490, -57.072]	[-81.540, -60.905]	[-82.710, -60.905]	[-82.760, -64.738]	[-83.930, -64.738]
400mH 5th	[-73.000, -69.390]	[-74.170, -69.390]	[-74.220, -72.909]	[-75.390, -72.909]	[-75.440, -76.741]	[-76.610, -76.741]	[-76.660, -80.574]	[-77.830, -80.574]	[-77.880, -84.407]	[-79.050, -84.407]	[-78.927, -88.216]	[-80.093, -88.321]	[-79.654, -91.999]	[-80.806, -92.202]	[-80.088, -95.731]	[-81.221, -96.025]	[-80.258, -99.395]	[-81.365, -99.775]
400mH 6th	[-67.740, -103.265]	[-68.742, -103.870]	[-67.194, -106.313]	[-68.146, -106.993]	[-66.312, -109.440]	[-67.208, -110.193]	[-65.257, -112.423]	[-66.095, -113.240]	[-64.053, -115.263]	[-64.832, -116.136]	[-62.722, -117.963]	[-63.443, -118.885]	[-61.285, -120.527]	[-61.947, -121.492]	[-59.757, -122.961]	[-60.361, -123.962]	[-58.153, -125.269]	[-58.701, -126.303]
400mH 7th	[-39.279, -120.784]	[-39.368, -121.950]	[-37.540, -122.095]	[-37.572, -123.265]	[-35.634, -123.320]	[-35.608, -124.490]	[-33.729, -124.454]	[-33.648, -125.621]	[-31.829, -125.505]	[-31.697, -126.668]	[-29.937, -126.481]	[-29.757, -127.637]	[-28.056, -127.388]	[-27.830, -128.537]	[-26.186, -128.233]	[-25.918, -129.372]	[-24.329, -129.020]	[-24.021, -130.149]
400mH 8th	[-8.488, -107.790]	[-7.590, -108.540]	[-7.060, -107.972]	[-6.147, -108.703]	[-5.603, -108.090]	[-4.674, -108.802]	[-4.157, -108.197]	[-3.215, -108.891]	[-2.724, -108.296]	[-1.769, -108.972]	[-1.301, -108.386]	[-0.335, -109.045]	[0.111, -108.470]	[1.088, -109.113]	[1.514, -108.547]	[2.501, -109.174]	[2.908, -108.618]	[3.905, -109.231]
400mH 9th	[0.000, -75.000]	[1.170, -75.000]	[1.220, -75.000]	[2.390, -75.000]	[2.440, -75.000]	[3.610, -75.000]	[3.660, -75.000]	[4.830, -75.000]	[4.880, -75.000]	[6.050, -75.000]	[6.100, -75.000]	[7.270, -75.000]	[7.320, -75.000]	[8.490, -75.000]	[8.540, -75.000]	[9.710, -75.000]	[9.760, -75.000]	[10.930, -75.000]
400mH 10th	[0.000, -40.000]	[1.170, -40.000]	[1.220, -40.000]	[2.390, -40.000]	[2.440, -40.000]	[3.610, -40.000]	[3.660, -40.000]	[4.830, -40.000]	[4.880, -40.000]	[6.050, -40.000]	[6.100, -40.000]	[7.270, -40.000]	[7.320, -40.000]	[8.490, -40.000]	[8.540, -40.000]	[9.710, -40.000]	[9.760, -40.000]	[10.930, -40.000]
Relay Takeover Zone *																		
4x100mR 2nd leg enterance	[-57.203, 30.060]	[-57.867, 31.024]	[-61.499, 28.246]	[-62.274, 29.122]	[-65.724, 25.735]	[-66.602, 26.508]	[-69.527, 22.848]	[-70.489, 23.514]	[-72.907, 19.667]	[-73.937, 20.223]	[-75.875, 16.259]	[-76.956, 16.706]	[-78.443, 12.685]	[-79.563, 13.023]	[-80.632, 8.994]	[-81.779, 9.228]	[-82.463, 5.228]	[-83.626, 5.361]
4x100mR 2nd leg exit	[-72.576, 5.543]	[-73.733, 5.720]	[-74.162, 2.079]	[-75.330, 2.144]	[-75.440, -1.741]	[-76.610, -1.741]	[-76.660, -5.574]	[-77.830, -5.574]	[-77.880, -9.407]	[-79.050, -9.407]	[-79.100, -13.240]	[-80.270, -13.240]	[-80.320, -17.072]	[-81.490, -17.072]	[-81.540, -20.905]	[-82.710, -20.905]	[-82.760, -24.738]	[-83.930, -24.738]
4x100mR 3rd leg enterance	[-73.000, -64.390]	[-74.170, -64.390]	[-74.220, -67.909]	[-75.390, -67.909]	[-75.440, -71.741]	[-76.610, -71.741]	[-76.660, -75.574]	[-77.830, -75.574]	[-77.880, -79.407]	[-79.050, -79.407]	[-79.100, -83.240]	[-80.270, -83.240]	[-80.238, -87.058]	[-81.406, -87.130]	[-81.073, -90.854]	[-82.231, -91.022]	[-81.617, -94.608]	[-82.758, -94.867]
4x100mR 3rd leg exit	[-71.660, -94.187]	[-72.787, -94.501]	[-71.848, -97.554]	[-72.944, -97.963]	[-71.675, -101.093]	[-72.732, -101.595]	[-71.253, -104.514]	[-72.266, -105.101]	[-70.613, -107.811]	[-71.578, -108.474]	[-69.783, -110.979]	[-70.697, -111.709]	[-68.787, -114.016]	[-69.649, -114.807]	[-67.648, -116.923]	[-68.457, -117.768]	[-66.384, -119.701]	[-67.140, -120.594]
4x100mR 4th leg enterance	[-15.796, -114.450]	[-15.133, -115.414]	[-14.225, -114.831]	[-13.534, -115.775]	[-12.595, -115.129]	[-11.877, -116.052]	[-10.984, -115.402]	[-10.240, -116.305]	[-9.390, -115.653]	[-8.624, -116.537]	[-7.814, -115.884]	[-7.026, -116.749]	[-6.253, -116.097]	[-5.445, -116.943]	[-4.707, -116.293]	[-3.881, -117.122]	[-3.176, -116.476]	[-2.333, -117.287]
4x100mR 4th leg exit	[-0.423, -89.933]	[0.733, -90.110]	[0.808, -89.950]	[1.965, -90.123]	[2.041, -89.952]	[3.199, -90.119]	[3.273, -89.954]	[4.431, -90.116]	[4.504, -89.956]	[5.663, -90.113]	[5.735, -89.958]	[6.895, -90.111]	[6.965, -89.959]	[8.125, -90.108]	[8.194, -89.961]	[9.355, -90.106]	[9.423, -89.962]	[10.585, -90.103]
4x400mR 2nd leg enterance	[0.000, -10.000]	[1.170, -10.000]	[1.220, -6.474]	[2.390, -6.474]	[2.440, -2.616]	[3.610, -2.616]	[3.640, 1.252]	[4.810, 1.289]	[4.563, 5.113]	[5.724, 5.258]	[5.149, 8.951]	[6.293, 9.197]	[5.427, 12.741]	[6.546, 13.081]	[5.423, 16.465]	[6.512, 16.892]	[5.162, 20.106]	[6.216, 20.615]
4x400mR 2nd leg exit	[-1.339, 9.797]	[-0.212, 10.111]	[-1.154, 13.171]	[-0.058, 13.580]	[-1.338, 16.732]	[-0.281, 17.235]	[-1.783, 20.189]	[-0.772, 20.777]	[-2.462, 23.531]	[-1.500, 24.197]	[-3.348, 26.753]	[-2.438, 27.488]	[-4.418, 29.849]	[-3.562, 30.646]	[-5.652, 32.817]	[-4.850, 33.670]	[-7.030, 35.658]	[-6.284, 36.560]
4x400mR 3rd/4th leg enterance	[0.000, -10.000]	[1.170, -10.000]	[1.220, -10.000]	[2.390, -10.000]	[2.440, -10.000]	[3.610, -10.000]	[3.660, -10.000]	[4.830, -10.000]	[4.880, -10.000]	[6.050, -10.000]	[6.100, -10.000]	[7.270, -10.000]	[7.320, -10.000]	[8.490, -10.000]	[8.540, -10.000]	[9.710, -10.000]	[9.760, -10.000]	[10.930, -10.000]
4x400mR 3rd/4th leg exit			[-0.130, 10.000]	[1.082, 10.000]	[1.134, 10.000]	[2.343, 10.000]	[2.395, 10.000]	[3.602, 10.000]	[3.654, 10.000]	[4.858, 10.000]								
Every 100m point around the lap of each lane *																		
100m	[-69.765, 15.023]	[-70.831, 15.504]	[-72.318, 11.825]	[-73.429, 12.192]	[-74.576, 8.156]	[-75.720, 8.401]	[-76.418, 4.395]	[-77.581, 4.523]	[-77.875, 0.590]	[-79.045, 0.607]	[-79.100, -3.240]	[-80.270, -3.240]	[-80.320, -7.072]	[-81.490, -7.072]	[-81.540, -10.905]	[-82.710, -10.905]	[-82.760, -14.738]	[-83.930, -14.738]
300m	[-3.235, -99.413]	[-2.169, -99.894]	[-1.931, -99.483]	[-0.859, -99.951]	[-0.616, -99.512]	[0.462, -99.966]	[0.693, -99.538]	[1.777, -99.980]	[1.998, -99.563]	[3.087, -99.992]	[3.298, -99.585]	[4.391, -100.002]	[4.594, -99.605]	[5.691, -100.012]	[5.885, -99.624]	[6.986, -100.020]	[7.173, -99.642]	[8.278, -100.028]
Analysis points **																		
100m point of 800m	[-69.765, 15.023]	[-70.831, 15.504]	[-71.071, 15.086]	[-72.144, 15.554]	[-72.396, 15.092]	[-73.475, 15.546]	[-73.721, 15.079]	[-74.805, 15.519]	[-75.046, 15.048]	[-76.136, 15.474]	[-76.372, 14.999]	[-77.467, 15.411]	[-77.697, 14.931]	[-78.797, 15.329]	[-79.023, 14.845]	[-80.128, 15.231]	[-80.348, 14.741]	[-81.457, 15.114]
100m point of 4x400mR 1st leg	[-69.765, 15.023]	[-70.831, 15.504]	[-73.261, 8.448]	[-74.402, 8.710]	[-75.430, 0.870]	[-76.600, 0.897]	[-76.660, -6.833]	[-77.830, -6.833]	[-77.880, -14.558]	[-79.050, -14.558]	[-79.100, -22.300]	[-80.270, -22.300]	[-80.320, -30.059]	[-81.490, -30.059]	[-81.540, -37.835]	[-82.710, -37.835]	[-82.760, -45.628]	[-83.930, -45.628]
200m point of 4x400mR 1st leg	[-73.000, -84.390]	[-74.170, -84.390]	[-73.571, -91.357]	[-74.720, -91.573]	[-72.713, -98.706]	[-73.801, -99.136]	[-70.609, -105.588]	[-71.603, -106.206]	[-67.458, -111.847]	[-68.333, -112.623]	[-63.453, -117.379]	[-64.193, -118.285]	[-58.778, -122.124]	[-59.373, -123.132]	[-53.599, -126.058]	[-54.043, -127.140]	[-48.066, -129.180]	[-48.359, -130.313]
300m point of 4x400mR 1st leg	[-3.235, -99.413]	[-2.169, -99.894]	[-0.679, -96.208]	[0.432, -96.574]	[1.583, -92.514]	[2.727, -92.758]	[3.427, -88.711]	[4.590, -88.837]	[4.877, -84.847]	[6.047, -84.860]	[6.100, -80.940]	[7.270, -80.940]	[7.320, -77.013]	[8.490, -77.013]	[8.540, -73.070]	[9.710, -73.070]	[9.760, -69.110]	[10.930, -69.110]

All x-coordinates and y-coordinates, left and right in each of the square brackets, respectively represent the intersection of each mark, the edge farther from the finish line and lane lines: inside−the intersection of the mark and the outer edge of the inside lane line; outside−the intersection of the mark and the inner edge of the outside lane line. Figure 1 presents related information.

* denotes marks that do not necessarily intersect with the lane lines, although coordinates of the intersection of the mark edge extension with the lane lines are listed.

** denotes that these marks do not exist on the track, but their coordinates were calculated and listed in the example race analysis conducted for this study.

Table 3. Coordinates of marks of the 80 m straight track.

Mark	Lane 1		Lane 2		Lane 3		Lane 4		Lane 5		Lane 6		Lane 7		Lane 8		Lane 9	
	inside	outside	inside	outside	inside	outside	inside	outside	inside	outside	inside	outside	inside	outside	inside	outside	inside	outside
Finish Line	[0.000, 0.000]	[1.170, 0.000]	[1.220, 0.000]	[2.390, 0.000]	[2.440, 0.000]	[3.610, 0.000]	[3.660, 0.000]	[4.830, 0.000]	[4.880, 0.000]	[6.050, 0.000]	[6.100, 0.000]	[7.270, 0.000]	[7.320, 0.000]	[8.490, 0.000]	[8.540, 0.000]	[9.710, 0.000]	[9.760, 0.000]	[10.930, 0.000]
Start Line																		
100m / 100mH	[0.000, -100.000]	[1.170, -100.000]	[1.220, -100.000]	[2.390, -100.000]	[2.440, -100.000]	[3.610, -100.000]	[3.660, -100.000]	[4.830, -100.000]	[4.880, -100.000]	[6.050, -100.000]	[6.100, -100.000]	[7.270, -100.000]	[7.320, -100.000]	[8.490, -100.000]	[8.540, -100.000]	[9.710, -100.000]	[9.760, -100.000]	[10.930, -100.000]
110mH	[0.000, -110.000]	[1.170, -110.000]	[1.220, -110.000]	[2.390, -110.000]	[2.440, -110.000]	[3.610, -110.000]	[3.660, -110.000]	[4.830, -110.000]	[4.880, -110.000]	[6.050, -110.000]	[6.100, -110.000]	[7.270, -110.000]	[7.320, -110.000]	[8.490, -110.000]	[8.540, -110.000]	[9.710, -110.000]	[9.760, -110.000]	[10.930, -110.000]
200m	[-75.794, -80.000]	[-76.964, -80.000]	[-76.858, -83.496]	[-78.023, -83.601]	[-77.573, -87.275]	[-78.724, -87.486]	[-77.973, -90.998]	[-79.101, -91.308]	[-78.090, -94.645]	[-79.189, -95.045]	[-77.953, -98.201]	[-79.018, -98.685]	[-77.592, -101.655]	[-78.619, -102.216]	[-77.029, -105.002]	[-78.015, -105.632]	[-76.289, -108.236]	[-77.232, -108.929]
400m / 4x100mR	[0.000, 0.000]	[1.170, 0.000]	[0.595, 6.964]	[1.746, 7.172]	[-0.184, 14.311]	[0.910, 14.727]	[-2.161, 21.212]	[-1.155, 21.809]	[-5.147, 27.519]	[-4.251, 28.272]	[-8.958, 33.140]	[-8.189, 34.022]	[-13.422, 38.021]	[-12.789, 39.004]	[-18.382, 42.138]	[-17.890, 43.199]	[-23.698, 45.493]	[-23.350, 46.610]
800m	[0.000, 0.000]	[1.170, 0.000]	[1.063, 3.504]	[2.228, 3.609]	[1.772, 7.308]	[2.923, 7.520]	[2.158, 11.073]	[3.285, 11.385]	[2.247, 14.777]	[3.345, 15.181]	[2.067, 18.402]	[3.130, 18.891]	[1.643, 21.935]	[2.666, 22.503]	[0.999, 25.367]	[1.979, 26.006]	[0.155, 28.692]	[1.090, 29.396]
4x400mR	[0.000, 0.000]	[1.170, 0.000]	[-0.183, 10.384]	[0.945, 10.694]	[-3.401, 20.908]	[-2.401, 21.514]	[-9.105, 29.967]	[-8.295, 30.811]	[-16.669, 37.138]	[-16.089, 38.154]	[-25.472, 42.206]	[-25.141, 43.329]	[-34.939, 45.120]	[-34.862, 46.288]	[-44.570, 45.955]	[-44.738, 47.113]	[-53.948, 44.873]	[-54.342, 45.974]
1500m	[-70.977, 19.099]	[-71.793, 19.425]	[-71.842, 19.440]	[-73.022, 19.731]	[-73.074, 19.741]	[-74.315, 19.915]	[-74.369, 19.921]	[-75.657, 19.995]	[-75.713, 19.996]	[-77.032, 19.996]	[-77.088, 19.995]	[-78.408, 19.973]	[-78.465, 19.972]	[-79.784, 19.932]	[-79.840, 19.930]	[-81.158, 19.873]	[-81.215, 19.870]	[-82.532, 19.794]
5000m	[-75.794, -80.000]	[-76.964, -80.125]	[-77.014, -80.136]	[-78.182, -80.475]	[-78.231, -80.492]	[-79.393, -80.961]	[-79.443, -80.984]	[-80.596, -81.564]	[-80.645, -81.591]	[-81.786, -82.270]	[-81.834, -82.301]	[-82.960, -83.074]	[-83.007, -83.109]	[-84.114, -83.971]	[-84.161, -84.010]	[-85.246, -84.957]	[-85.291, -84.999]	[-86.351, -86.030]
5000m outer group									[-78.041, -94.777]	[-79.091, -95.311]	[-79.134, -95.339]	[-80.116, -96.051]	[-80.157, -96.084]	[-81.094, -96.907]	[-81.133, -96.944]	[-82.028, -97.859]	[-82.065, -97.900]	[-82.919, -98.897]
5000m outer group with temporal kerb									[-77.943, -95.042]	[-78.996, -95.564]	[-79.039, -95.591]	[-80.021, -96.299]	[-80.062, -96.331]	[-80.997, -97.152]	[-81.036, -97.189]	[-81.929, -98.102]	[-81.966, -98.143]	[-82.817, -99.138]
10000m	[0.000, 0.000]	[1.170, 0.125]	[1.220, 0.136]	[2.387, 0.475]	[2.437, 0.492]	[3.599, 0.961]	[3.648, 0.984]	[4.801, 1.564]	[4.850, 1.591]	[5.991, 2.270]	[6.040, 2.301]	[7.165, 3.074]	[7.213, 3.109]	[8.320, 3.971]	[8.367, 4.010]	[9.451, 4.957]	[9.497, 4.999]	[10.556, 6.030]
10000m outer group									[2.247, 14.777]	[3.296, 15.311]	[3.340, 15.339]	[4.322, 16.051]	[4.363, 16.084]	[5.299, 16.907]	[5.338, 16.944]	[6.233, 17.859]	[6.271, 17.900]	[7.125, 18.897]
5000m outer group with temporal kerb									[2.148, 15.042]	[3.202, 15.564]	[3.245, 15.591]	[4.227, 16.299]	[4.268, 16.331]	[5.203, 17.152]	[5.242, 17.189]	[6.134, 18.102]	[6.172, 18.143]	[7.023, 19.138]
Break Line			[-77.014, -0.005]	[-78.184, -0.027]	[-78.234, -0.029]	[-79.404, -0.068]	[-79.454, -0.070]	[-80.624, -0.127]	[-80.674, -0.130]	[-81.844, -0.205]	[-81.894, -0.208]	[-83.064, -0.300]	[-83.114, -0.304]	[-84.284, -0.414]	[-84.334, -0.419]	[-85.504, -0.545]	[-85.554, -0.551]	[-86.724, -0.695]
Break Point								[4.830, -80.000]	[4.880, -80.000]									
Hurdle																		
100mH 1st	[0.000, -87.000]	[1.170, -87.000]	[1.220, -87.000]	[2.390, -87.000]	[2.440, -87.000]	[3.610, -87.000]	[3.660, -87.000]	[4.830, -87.000]	[4.880, -87.000]	[6.050, -87.000]	[6.100, -87.000]	[7.270, -87.000]	[7.320, -87.000]	[8.490, -87.000]	[8.540, -87.000]	[9.710, -87.000]	[9.760, -87.000]	[10.930, -87.000]
100mH 2st	[0.000, -78.500]	[1.170, -78.500]	[1.220, -78.500]	[2.390, -78.500]	[2.440, -78.500]	[3.610, -78.500]	[3.660, -78.500]	[4.830, -78.500]	[4.880, -78.500]	[6.050, -78.500]	[6.100, -78.500]	[7.270, -78.500]	[7.320, -78.500]	[8.490, -78.500]	[8.540, -78.500]	[9.710, -78.500]	[9.760, -78.500]	[10.930, -78.500]
100mH 3st	[0.000, -70.000]	[1.170, -70.000]	[1.220, -70.000]	[2.390, -70.000]	[2.440, -70.000]	[3.610, -70.000]	[3.660, -70.000]	[4.830, -70.000]	[4.880, -70.000]	[6.050, -70.000]	[6.100, -70.000]	[7.270, -70.000]	[7.320, -70.000]	[8.490, -70.000]	[8.540, -70.000]	[9.710, -70.000]	[9.760, -70.000]	[10.930, -70.000]
100mH 4st	[0.000, -61.500]	[1.170, -61.500]	[1.220, -61.500]	[2.390, -61.500]	[2.440, -61.500]	[3.610, -61.500]	[3.660, -61.500]	[4.830, -61.500]	[4.880, -61.500]	[6.050, -61.500]	[6.100, -61.500]	[7.270, -61.500]	[7.320, -61.500]	[8.490, -61.500]	[8.540, -61.500]	[9.710, -61.500]	[9.760, -61.500]	[10.930, -61.500]
100mH 5st	[0.000, -53.000]	[1.170, -53.000]	[1.220, -53.000]	[2.390, -53.000]	[2.440, -53.000]	[3.610, -53.000]	[3.660, -53.000]	[4.830, -53.000]	[4.880, -53.000]	[6.050, -53.000]	[6.100, -53.000]	[7.270, -53.000]	[7.320, -53.000]	[8.490, -53.000]	[8.540, -53.000]	[9.710, -53.000]	[9.760, -53.000]	[10.930, -53.000]
100mH 6st	[0.000, -44.500]	[1.170, -44.500]	[1.220, -44.500]	[2.390, -44.500]	[2.440, -44.500]	[3.610, -44.500]	[3.660, -44.500]	[4.830, -44.500]	[4.880, -44.500]	[6.050, -44.500]	[6.100, -44.500]	[7.270, -44.500]	[7.320, -44.500]	[8.490, -44.500]	[8.540, -44.500]	[9.710, -44.500]	[9.760, -44.500]	[10.930, -44.500]
100mH 7st	[0.000, -36.000]	[1.170, -36.000]	[1.220, -36.000]	[2.390, -36.000]	[2.440, -36.000]	[3.610, -36.000]	[3.660, -36.000]	[4.830, -36.000]	[4.880, -36.000]	[6.050, -36.000]	[6.100, -36.000]	[7.270, -36.000]	[7.320, -36.000]	[8.490, -36.000]	[8.540, -36.000]	[9.710, -36.000]	[9.760, -36.000]	[10.930, -36.000]
100mH 8st	[0.000, -27.500]	[1.170, -27.500]	[1.220, -27.500]	[2.390, -27.500]	[2.440, -27.500]	[3.610, -27.500]	[3.660, -27.500]	[4.830, -27.500]	[4.880, -27.500]	[6.050, -27.500]	[6.100, -27.500]	[7.270, -27.500]	[7.320, -27.500]	[8.490, -27.500]	[8.540, -27.500]	[9.710, -27.500]	[9.760, -27.500]	[10.930, -27.500]
100mH 9st	[0.000, -19.000]	[1.170, -19.000]	[1.220, -19.000]	[2.390, -19.000]	[2.440, -19.000]	[3.610, -19.000]	[3.660, -19.000]	[4.830, -19.000]	[4.880, -19.000]	[6.050, -19.000]	[6.100, -19.000]	[7.270, -19.000]	[7.320, -19.000]	[8.490, -19.000]	[8.540, -19.000]	[9.710, -19.000]	[9.760, -19.000]	[10.930, -19.000]
100mH 10st	[0.000, -10.500]	[1.170, -10.500]	[1.220, -10.500]	[2.390, -10.500]	[2.440, -10.500]	[3.610, -10.500]	[3.660, -10.500]	[4.830, -10.500]	[4.880, -10.500]	[6.050, -10.500]	[6.100, -10.500]	[7.270, -10.500]	[7.320, -10.500]	[8.490, -10.500]	[8.540, -10.500]	[9.710, -10.500]	[9.760, -10.500]	[10.930, -10.500]
110mH 1st	[0.000, -96.280]	[1.170, -96.280]	[1.220, -96.280]	[2.390, -96.280]	[2.440, -96.280]	[3.610, -96.280]	[3.660, -96.280]	[4.830, -96.280]	[4.880, -96.280]	[6.050, -96.280]	[6.100, -96.280]	[7.270, -96.280]	[7.320, -96.280]	[8.490, -96.280]	[8.540, -96.280]	[9.710, -96.280]	[9.760, -96.280]	[10.930, -96.280]
110mH 2st	[0.000, -87.140]	[1.170, -87.140]	[1.220, -87.140]	[2.390, -87.140]	[2.440, -87.140]	[3.610, -87.140]	[3.660, -87.140]	[4.830, -87.140]	[4.880, -87.140]	[6.050, -87.140]	[6.100, -87.140]	[7.270, -87.140]	[7.320, -87.140]	[8.490, -87.140]	[8.540, -87.140]	[9.710, -87.140]	[9.760, -87.140]	[10.930, -87.140]
110mH 3st	[0.000, -78.000]	[1.170, -78.000]	[1.220, -78.000]	[2.390, -78.000]	[2.440, -78.000]	[3.610, -78.000]	[3.660, -78.000]	[4.830, -78.000]	[4.880, -78.000]	[6.050, -78.000]	[6.100, -78.000]	[7.270, -78.000]	[7.320, -78.000]	[8.490, -78.000]	[8.540, -78.000]	[9.710, -78.000]	[9.760, -78.000]	[10.930, -78.000]
110mH 4st	[0.000, -68.860]	[1.170, -68.860]	[1.220, -68.860]	[2.390, -68.860]	[2.440, -68.860]	[3.610, -68.860]	[3.660, -68.860]	[4.830, -68.860]	[4.880, -68.860]	[6.050, -68.860]	[6.100, -68.860]	[7.270, -68.860]	[7.320, -68.860]	[8.490, -68.860]	[8.540, -68.860]	[9.710, -68.860]	[9.760, -68.860]	[10.930, -68.860]
110mH 5st	[0.000, -59.720]	[1.170, -59.720]	[1.220, -59.720]	[2.390, -59.720]	[2.440, -59.720]	[3.610, -59.720]	[3.660, -59.720]	[4.830, -59.720]	[4.880, -59.720]	[6.050, -59.720]	[6.100, -59.720]	[7.270, -59.720]	[7.320, -59.720]	[8.490, -59.720]	[8.540, -59.720]	[9.710, -59.720]	[9.760, -59.720]	[10.930, -59.720]
110mH 6st	[0.000, -50.580]	[1.170, -50.580]	[1.220, -50.580]	[2.390, -50.580]	[2.440, -50.580]	[3.610, -50.580]	[3.660, -50.580]	[4.830, -50.580]	[4.880, -50.580]	[6.050, -50.580]	[6.100, -50.580]	[7.270, -50.580]	[7.320, -50.580]	[8.490, -50.580]	[8.540, -50.580]	[9.710, -50.580]	[9.760, -50.580]	[10.930, -50.580]
110mH 7st	[0.000, -41.440]	[1.170, -41.440]	[1.220, -41.440]	[2.390, -41.440]	[2.440, -41.440]	[3.610, -41.440]	[3.660, -41.440]	[4.830, -41.440]	[4.880, -41.440]	[6.050, -41.440]	[6.100, -41.440]	[7.270, -41.440]	[7.320, -41.440]	[8.490, -41.440]	[8.540, -41.440]	[9.710, -41.440]	[9.760, -41.440]	[10.930, -41.440]
110mH 8st	[0.000, -32.300]	[1.170, -32.300]	[1.220, -32.300]	[2.390, -32.300]	[2.440, -32.300]	[3.610, -32.300]	[3.660, -32.300]	[4.830, -32.300]	[4.880, -32.300]	[6.050, -32.300]	[6.100, -32.300]	[7.270, -32.300]	[7.320, -32.300]	[8.490, -32.300]	[8.540, -32.300]	[9.710, -32.300]	[9.760, -32.300]	[10.930, -32.300]
110mH 9st	[0.000, -23.160]	[1.170, -23.160]	[1.220, -23.160]	[2.390, -23.160]	[2.440, -23.160]	[3.610, -23.160]	[3.660, -23.160]	[4.830, -23.160]	[4.880, -23.160]	[6.050, -23.160]	[6.100, -23.160]	[7.270, -23.160]	[7.320, -23.160]	[8.490, -23.160]	[8.540, -23.160]	[9.710, -23.160]	[9.760, -23.160]	[10.930, -23.160]
110mH 10st	[0.000, -14.020]	[1.170, -14.020]	[1.220, -14.020]	[2.390, -14.020]	[2.440, -14.020]	[3.610, -14.020]	[3.660, -14.020]	[4.830, -14.020]	[4.880, -14.020]	[6.050, -14.020]	[6.100, -14.020]	[7.270, -14.020]	[7.320, -14.020]	[8.490, -14.020]	[8.540, -14.020]	[9.710, -14.020]	[9.760, -14.020]	[10.930, -14.020]
400mH 1st	[-23.395, 35.012]	[-22.947, 36.093]	[-28.323, 37.927]	[-28.036, 39.062]	[-33.950, 40.144]	[-33.836, 41.308]	[-39.664, 41.520]	[-39.714, 42.689]	[-45.349, 42.123]	[-45.553, 43.275]	[-50.914, 42.028]	[-51.260, 43.145]	[-56.288, 41.308]	[-56.764, 42.377]	[-61.420, 40.039]	[-62.013, 41.047]	[-66.272, 38.289]	[-66.969, 39.229]
400mH 2nd	[-56.846, 32.820]	[-57.431, 33.833]	[-61.349, 31.307]	[-62.051, 32.244]	[-65.844, 29.087]	[-66.654, 29.931]	[-69.946, 26.455]	[-70.848, 27.200]	[-73.648, 23.490]	[-74.626, 24.132]	[-76.952, 20.260]	[-77.991, 20.799]	[-79.867, 16.827]	[-80.953, 17.262]	[-82.407, 13.241]	[-83.528, 13.574]	[-84.588, 9.547]	[-85.735, 9.781]
400mH 3rd	[-75.470, 4.947]	[-76.630, 5.099]	[-76.987, 1.474]	[-78.156, 1.518]	[-78.234, -2.351]	[-79.404, -2.351]	[-79.454, -6.184]	[-80.624, -6.184]	[-80.674, -10.017]	[-81.844, -10.017]	[-81.894, -13.850]	[-83.064, -13.850]	[-83.114, -17.682]	[-84.284, -17.682]	[-84.334, -21.515]	[-85.504, -21.515]	[-85.554, -25.348]	[-86.724, -25.348]
400mH 4th	[-75.794, -30.000]	[-76.964, -30.000]	[-77.014, -33.519]	[-78.184, -33.519]	[-78.234, -37.351]	[-79.404, -37.351]	[-79.454, -41.184]	[-80.624, -41.184]	[-80.674, -45.017]	[-81.844, -45.017]	[-81.894, -48.850]	[-83.064, -48.850]	[-83.114, -52.682]	[-84.284, -52.682]	[-84.334, -56.515]	[-85.504, -56.515]	[-85.554, -60.348]	[-86.724, -60.348]
400mH 5th	[-75.794, -65.000]	[-76.964, -65.000]	[-77.014, -68.519]	[-78.184, -68.519]	[-78.234, -72.351]	[-79.404, -72.351]	[-79.454, -76.184]	[-80.624, -76.184]	[-80.674, -80.017]	[-81.844, -80.017]	[-81.728, -83.827]	[-82.893, -83.929]	[-82.469, -87.612]	[-83.622, -87.809]	[-82.926, -91.350]	[-84.061, -91.635]	[-83.125, -95.023]	[-84.235, -95.392]
400mH 6th	[-70.717, -98.949]	[-71.730, -99.534]	[-70.222, -102.028]	[-71.189, -102.687]	[-69.396, -105.198]	[-70.309, -105.929]	[-68.395, -108.229]	[-69.253, -109.024]	[-67.244, -111.124]	[-68.046, -111.975]	[-65.964, -113.882]	[-66.710, -114.783]	[-64.574, -116.510]	[-65.264, -117.454]	[-63.090, -119.010]	[-63.724, -119.993]	[-61.526, -121.387]	[-62.106, -122.403]
400mH 7th	[-42.844, -117.573]	[-42.996, -118.733]	[-41.118, -118.984]	[-41.214, -120.150]	[-39.215, -120.316]	[-39.253, -121.485]	[-37.308, -121.553]	[-37.291, -122.723]	[-35.402, -122.704]	[-35.334, -123.872]	[-33.500, -123.777]	[-33.383, -124.941]	[-31.604, -124.777]	[-31.442, -125.936]	[-29.718, -125.711]	[-29.512, -126.863]	[-27.842, -126.584]	[-27.595, -127.728]
400mH 8th	[-11.100, -106.797]	[-10.273, -107.625]	[-9.625, -107.034]	[-8.780, -107.843]	[-8.111, -107.201]	[-7.247, -107.990]	[-6.612, -107.353]	[-5.731, -108.123]	[-5.126, -107.494]	[-4.229, -108.246]	[-3.652, -107.623]	[-2.742, -108.358]	[-2.191, -107.743]	[-1.267, -108.461]	[-0.741, -107.853]	[0.195, -108.555]	[0.699, -107.956]	[1.647, -108.642]
400mH 9th	[0.000, -75.000]	[1.170, -75.000]	[1.220, -75.000]	[2.390, -75.000]	[2.440, -75.000]	[3.610, -75.000]	[3.660, -75.000]	[4.830, -75.000]	[4.880, -75.000]	[6.050, -75.000]	[6.100, -75.000]	[7.270, -75.000]	[7.320, -75.000]	[8.490, -75.000]	[8.540, -75.000]	[9.710, -75.000]	[9.760, -75.000]	[10.930, -75.000]
400mH 10th	[0.000, -40.000]	[1.170, -40.000]	[1.220, -40.000]	[2.390, -40.000]	[2.440, -40.000]	[3.610, -40.000]	[3.660, -40.000]	[4.830, -40.000]	[4.880, -40.000]	[6.050, -40.000]	[6.100, -40.000]	[7.270, -40.000]	[7.320, -40.000]	[8.490, -40.000]	[8.540, -40.000]	[9.710, -40.000]	[9.760, -40.000]	[10.930, -40.000]
Relay Takeover Zone *																		
4x100mR 2nd leg enterance	[-56.846, 32.820]	[-57.431, 33.833]	[-61.349, 31.307]	[-62.051, 32.244]	[-65.844, 29.087]	[-66.654, 29.931]	[-69.946, 26.455]	[-70.848, 27.200]	[-73.648, 23.490]	[-74.626, 24.132]	[-76.952, 20.260]	[-77.991, 20.799]	[-79.867, 16.827]	[-80.953, 17.262]	[-82.407, 13.241]	[-83.528, 13.574]	[-84.588, 9.547]	[-85.735, 9.781]
4x100mR 2nd leg exit	[-74.503, 9.809]	[-75.633, 10.111]	[-76.484, 6.419]	[-77.638, 6.611]	[-78.148, 2.634]	[-79.316, 2.710]	[-79.454, -1.184]	[-80.624, -1.184]	[-80.674, -5.017]	[-81.844, -5.017]	[-81.894, -8.850]	[-83.064, -8.850]	[-83.114, -12.682]	[-84.284, -12.682]	[-84.334, -16.515]	[-85.504, -16.515]	[-85.554, -20.348]	[-86.724, -20.348]
4x100mR 3rd leg enterance	[-75.794, -60.000]	[-76.964, -60.000]	[-77.014, -63.519]	[-78.184, -63.519]	[-78.234, -67.351]	[-79.404, -67.351]	[-79.454, -71.184]	[-80.624, -71.184]	[-80.674, -75.017]	[-81.844, -75.017]	[-81.894, -78.850]	[-83.064, -78.850]	[-83.036, -82.669]	[-84.203, -82.738]	[-83.882, -86.466]	[-85.041, -86.629]	[-84.445, -90.224]	[-85.587, -90.475]
4x100mR 3rd leg exit	[-74.503, -89.809]	[-75.633, -90.111]	[-74.725, -93.186]	[-75.826, -93.581]	[-74.595, -96.743]	[-75.660, -97.229]	[-74.220, -100.190]	[-75.243, -100.758]	[-73.630, -103.518]	[-74.607, -104.161]	[-72.849, -106.723]	[-73.779, -107.433]	[-71.904, -109.802]	[-72.784, -110.573]	[-70.813, -112.756]	[-71.643, -113.581]	[-69.597, -115.586]	[-70.375, -116.459]
4x100mR 4th leg enterance	[-18.949, -112.820]	[-18.364, -113.833]	[-17.337, -113.278]	[-16.722, -114.273]	[-15.655, -113.651]	[-15.010, -114.627]	[-13.993, -113.994]	[-13.320, -114.951]	[-12.348, -114.310]	[-11.650, -115.248]	[-10.722, -114.601]	[-9.999, -115.522]	[-9.112, -114.871]	[-8.367, -115.774]	[-7.518, -115.122]	[-6.753, -116.007]	[-5.940, -115.354]	[-5.155, -116.222]
4x100mR 4th leg exit	[-1.291, -89.809]	[-0.161, -90.111]	[-0.038, -89.842]	[1.094, -90.137]	[1.219, -89.850]	[2.353, -90.136]	[2.474, -89.857]	[3.611, -90.135]	[3.727, -89.864]	[4.866, -90.134]	[4.979, -89.870]	[6.119, -90.132]	[6.228, -89.876]	[7.370, -90.131]	[7.477, -89.881]	[8.620, -90.130]	[8.723, -89.886]	[9.868, -90.129]
4x400mR 2nd leg enterance	[0.000, -10.000]	[1.170, -10.000]	[1.220, -6.474]	[2.390, -6.474]	[2.440, -2.615]	[3.610, -2.615]	[3.641, 1.256]	[4.810, 1.292]	[4.572, 5.122]	[5.734, 5.262]	[5.176, 8.967]	[6.322, 9.206]	[5.479, 12.770]	[6.602, 13.100]	[5.506, 16.510]	[6.600, 16.926]	[5.279, 20.174]	[6.339, 20.669]
4x400mR 2nd leg exit	[-1.291, 9.809]	[-0.161, 10.111]	[-1.072, 13.194]	[0.029, 13.588]	[-1.213, 16.774]	[-0.149, 17.261]	[-1.612, 20.258]	[-0.591, 20.829]	[-2.242, 23.635]	[-1.267, 24.282]	[-3.080, 26.898]	[-2.154, 27.613]	[-4.102, 30.041]	[-3.228, 30.819]	[-5.289, 33.063]	[-4.468, 33.896]	[-6.624, 35.961]	[-5.856, 36.844]
4x400mR 3rd/4th leg enterance	[0.000, -10.000]	[1.170, -10.000]	[1.220, -10.000]	[2.390, -10.000]	[2.440, -10.000]	[3.610, -10.000]	[3.660, -10.000]	[4.830, -10.000]	[4.880, -10.000]	[6.050, -10.000]	[6.100, -10.000]	[7.270, -10.000]	[7.320, -10.000]	[8.490, -10.000]	[8.540, -10.000]	[9.710, -10.000]	[9.760, -10.000]	[10.930, -10.000]
4x400mR 3rd/4th leg exit			[-0.080, 10.000]	[1.129, 10.000]	[1.181, 10.000]	[2.387, 10.000]	[2.439, 10.000]	[3.643, 10.000]	[3.695, 10.000]	[4.897, 10.000]								
Every 100m point around the lap of each lane *																		
100m	[-70.717, 18.949]	[-71.730, 19.534]	[-73.628, 15.922]	[-74.696, 16.398]	[-76.287, 12.383]	[-77.400, 12.742]	[-78.532, 8.709]	[-79.676, 8.954]	[-80.387, 4.949]	[-81.549, 5.084]	[-81.879, 1.145]	[-83.049, 1.176]	[-83.114, -2.682]	[-84.284, -2.682]	[-84.334, -6.515]	[-85.504, -6.515]	[-85.554, -10.348]	[-86.724, -10.348]
300m	[-5.077, -98.949]	[-4.064, -99.534]	[-3.733, -99.051]	[-2.711, -99.621]	[-2.371, -99.104]	[-1.340, -99.658]	[-1.016, -99.152]	[0.022, -99.691]	[0.331, -99.196]	[1.377, -99.721]	[1.672, -99.237]	[2.724, -99.748]	[3.006, -99.275]	[4.065, -99.773]	[4.335, -99.309]	[5.399, -99.796]	[5.659, -99.342]	[6.728, -99.817]
Analysis points **																		
100m point of 800m	[-70.717, 18.949]	[-71.730, 19.534]	[-72.065, 19.044]	[-73.087, 19.614]	[-73.440, 19.074]	[-74.471, 19.627]	[-74.814, 19.082]	[-75.854, 19.620]	[-76.188, 19.070]	[-77.236, 19.592]	[-77.562, 19.038]	[-78.617, 19.544]	[-78.936, 18.985]	[-79.997, 19.477]	[-80.308, 18.913]	[-81.377, 19.390]	[-81.680, 18.821]	[-82.755, 19.283]
100m point of 4x400mR 1st leg	[-70.717, 18.949]	[-71.730, 19.534]	[-74.910, 12.657]	[-76.017, 13.036]	[-77.895, 5.223]	[-79.055, 5.374]	[-79.454, -2.447]	[-80.624, -2.447]	[-80.674, -10.175]	[-81.844, -10.175]	[-81.894, -17.921]	[-83.064, -17.921]	[-83.114, -25.685]	[-84.284, -25.685]	[-84.334, -33.467]	[-85.504, -33.467]	[-85.554, -41.266]	[-86.724, -41.266]
200m point of 4x400mR 1st leg	[-75.794, -80.000]	[-76.964, -80.000]	[-76.388, -86.972]	[-77.539, -87.180]	[-75.598, -94.343]	[-76.692, -94.759]	[-73.593, -101.279]	[-74.598, -101.878]	[-70.557, -107.627]	[-71.450, -108.383]	[-66.669, -113.285]	[-67.434, -114.171]	[-62.103, -118.192]	[-62.729, -119.181]	[-57.017, -122.318]	[-57.499, -123.385]	[-51.553, -125.659]	[-51.888, -126.780]
300m point of 4x400mR 1st leg	[-5.077, -98.949]	[-4.064, -99.534]	[-2.164, -95.914]	[-1.095, -96.390]	[0.503, -92.351]	[1.616, -92.709]	[2.754, -88.632]	[3.898, -88.875]	[4.609, -84.809]	[5.771, -84.941]	[6.090, -80.924]	[7.260, -80.949]	[7.320, -76.997]	[8.490, -76.997]	[8.540, -73.048]	[9.710, -73.048]	[9.760, -69.082]	[10.930, -69.082]

All x-coordinates and y-coordinates, left and right in each of the square brackets, respectively represent the intersection of each mark, the edge farther from the finish line and lane lines: inside−the intersection of the mark and the outer edge of the inside lane line; outside−the intersection of the mark and the inner edge of the outside lane line. Figure 1 presents related information.

* denotes marks that do not necessarily intersect with the lane lines, although coordinates of the intersection of the mark edge extension with the lane lines are listed.

** denotes that these marks do not exist on the track, but their coordinates were calculated and listed in the example race analysis conducted for this study.

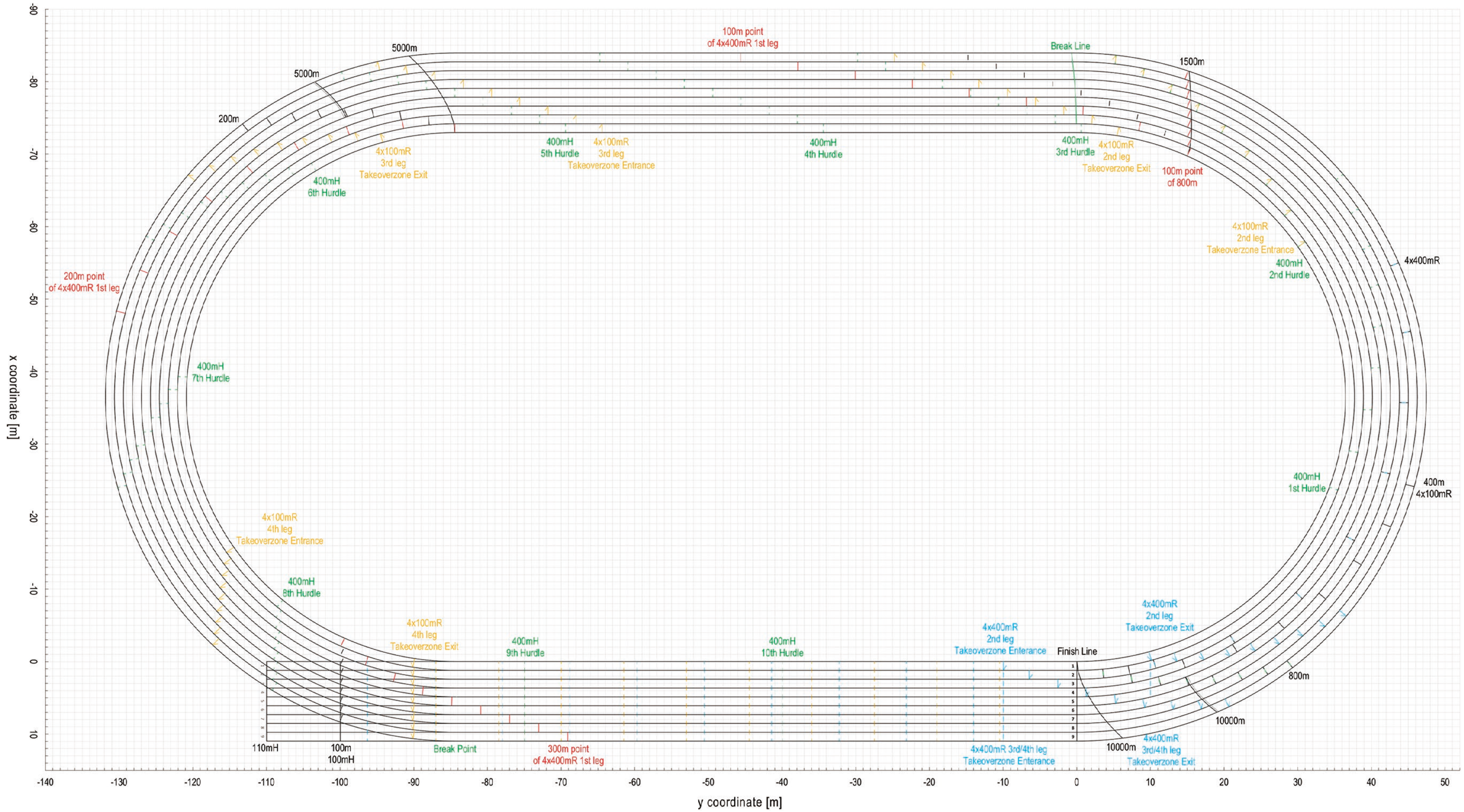


Figure 12. Schematic of World Athletics standard track drawn according to the mark coordinates obtained from this study.
The vertical and horizontal scales represent the x- and y-coordinates of the provisional coordinate system used in this study, with its origin positioned at the intersection of the finish line and the kerb edge. The outer start lines for 10000 m and 5000 m races with a temporary kerb are represented by gray lines. The red lines, i.e., 100 m points of 800 m, and 100 m, 200 m, 300 m points of the 4 × 400 m first leg are not actually marked on the track.

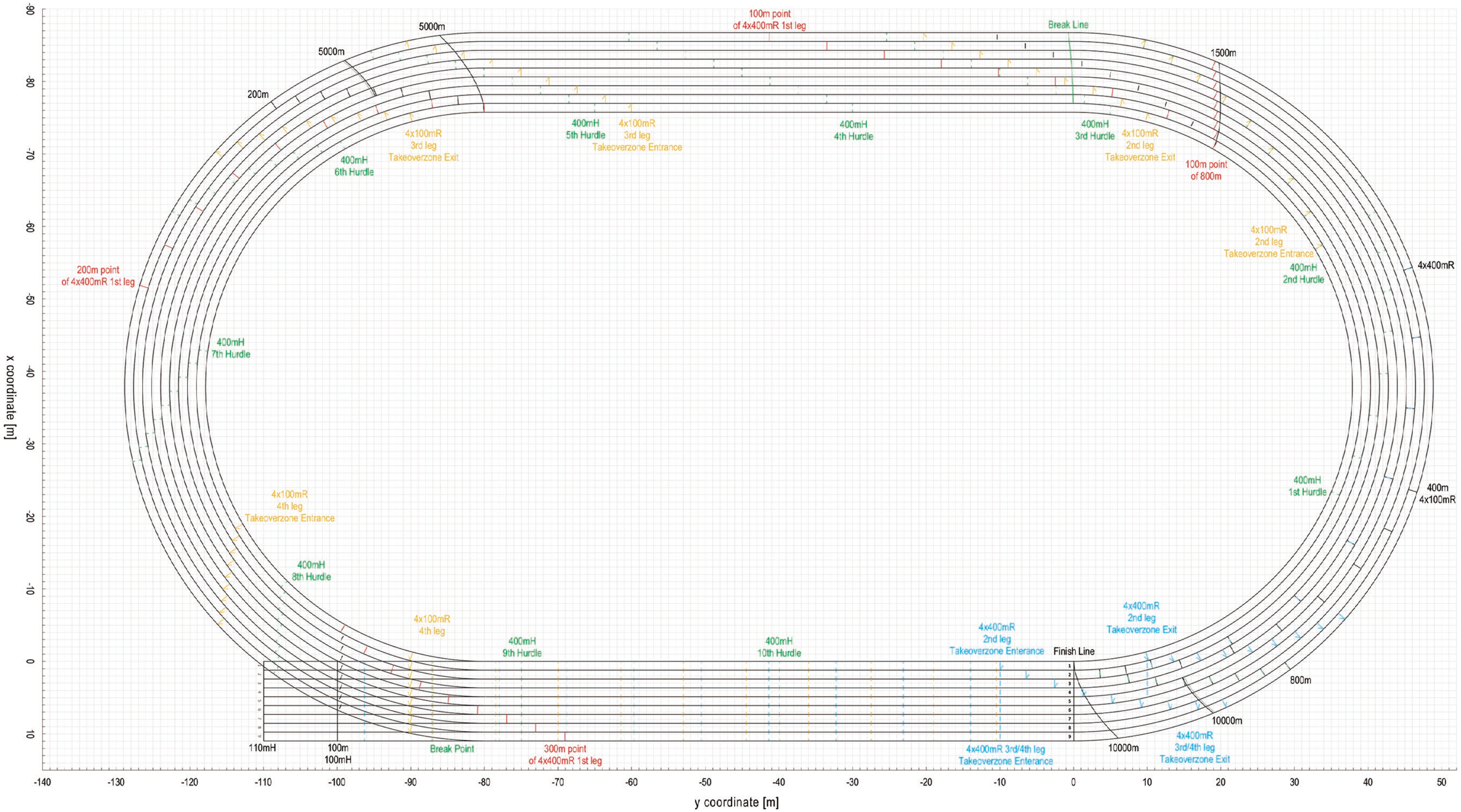


Figure 13. Schematic of the track with 80 m straight drawn according to the mark coordinates obtained from this study.
The vertical and horizontal scales represent the x- and y-coordinates of the provisional coordinate system used in this study, with its origin positioned at the intersection of the finish line and the kerb edge. The outer start lines for 10000 m and 5000 m races with a temporary kerb are represented by gray lines. The red lines, i.e., 100 m points of 800 m, and 100 m, 200 m, 300 m points of the 4 × 400 m first leg are not actually marked on the track.

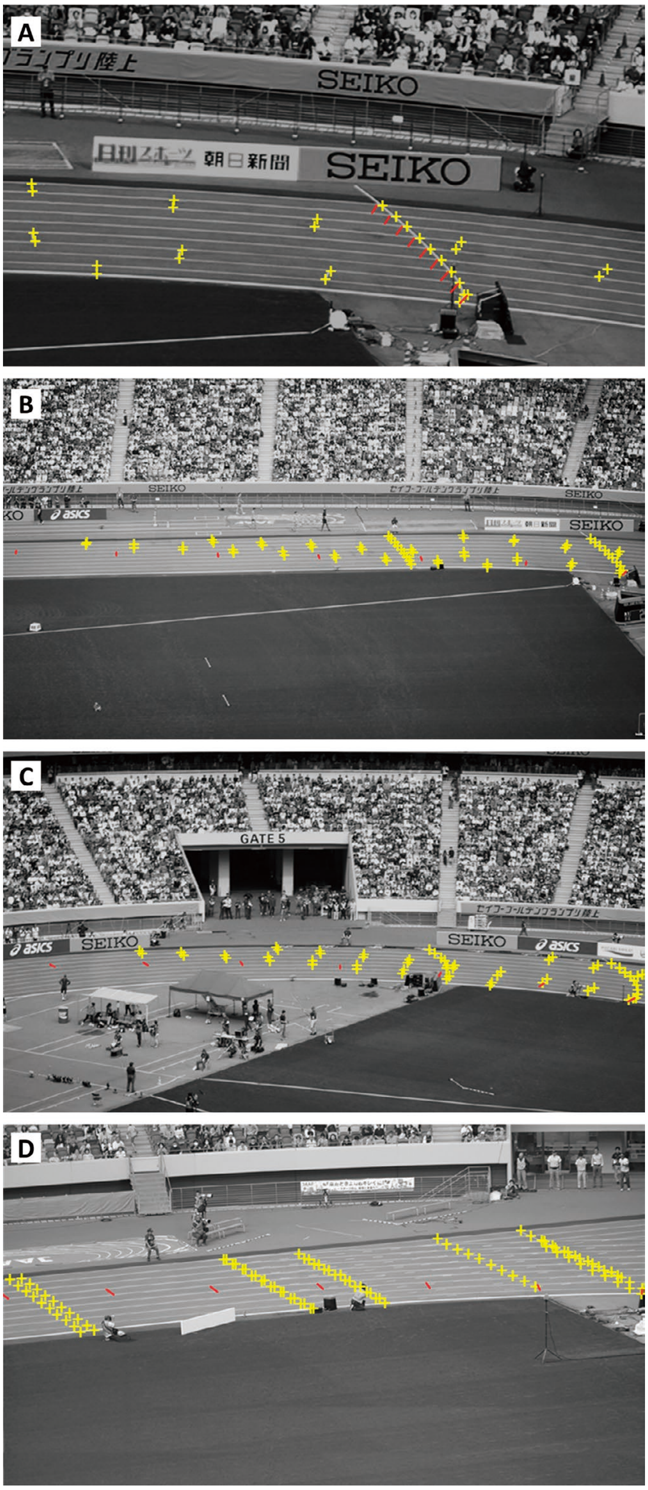


Figure 14. Images of the points for example race analysis.
A, the 100 m point in 800 m race in each lane. **B**–**D** respectively represent the 100 m, 200 m, and 300 m points of the first leg of 4 × 400 m relay in the lanes. Yellow marks represent the position of reference marks. Red lines represent the analysis points, connecting the analysis points identified on the edges of both inside and outside lane lines.

Table 4. Accuracy of analysis-point position identification.

Image and Analysis Point	N of marks	Error [m]
100 m point in 800 m race	29	0.043 ± 0.020
100 m point of 1st leg in 4 × 400 m relay race	62	0.037 ± 0.023
200 m point of 1st leg in 4 × 400 m relay race	57	0.041 ± 0.025
300 m point of 1st leg in 4 × 400 m relay race	96	0.040 ± 0.025
All	244	0.040 ± 0.024

line should be located within lane 7 (Figure 12). If SL_C is 80 m, then the edge of the 100 m start line should be located very close to the inside lane line of lane 5. The edge of 110 m hurdle start line is expected to be located within lane 9 (Figure 13). Other elements of the track layout include, for example, the lane width and the presence of the kerb. Regarding tracks constructed in recent years, these elements have been standardized (1.22 m of the lane width with the kerb), meaning that these factors are less critically important.

Accurate analysis-point identification requires that one obtain a precise matrix of coordinate transformation homography. To achieve this objective, it is necessary to ensure that a sufficient number of reference marks are recognizable in a photographed or filmed image. A minimum of four reference marks is required, although a greater number would yield more precise results. Ideally, the reference marks should surround the analysis point. Otherwise, the position of the analysis point would be extrapolated from the reference marks, which might reduce the accuracy of the analysis-point coordinates. The image resolution is also important because sufficient resolution is necessary for precise identification of the reference marks on the image. High-resolution images such as 4K are preferred, although the image resolution generally entails a tradeoff with the filming frame rate. Some areas of a track have sparse mark coverage. For example, in the middle of the back straight and the middle of the second curve, there are only 400 m hurdle marks at 35 m intervals. One might consider zooming out to increase the number of reference marks in the image. However, zooming out would decrease the relative resolution around reference marks. It might also make a reference mark on the image unrecognizable. Actually, regarding the practical race analysis example addressed in this study, the 400 m hurdle mark positions were not recognizable on the images near the 100 m and 200 m points of the first leg in 4×400 m relay because of the wide angle of view (Figure 14B and 14C). Various factors such as image resolution, time resolution, and field range of view must be balanced and set appropriately.

The examination presented in this study revealed that the methods applied for the two race analysis examples can identify the position of analysis point with a high degree of accuracy. The average error of 0.040 m in point position identification implies that the error in time measurement using this identified point would ideally be less than 0.01 s for an athlete running at 4 m/s or greater velocity. Most athletes of any gender or age category would meet this running velocity. Therefore, the accuracy of point position identification is deemed sufficient for the purpose of conducting race analysis. In practice, besides point position identification, other factors can also introduce errors in time measurement, such as the camera angle at which the photograph is taken relative to the running direction at the analysis point. As illustrated in the images of race analysis examples (Figure 14), a significant proportion of the analysis-point lines were projected obliquely, rather than vertically onto the image. This suggests that the camera was not positioned perpendicular to the running direction at these points. It is imperative that time measurement accounts for this camera angle. Projecting the analysis point as a line facilitates the understanding of the camera angle and ensures the accuracy of the time measurement.

This study presented two track mark coordinate calculation practices and two examples of analysis-point position identification. In both example races, i.e., 800 m or 4×400 m relay, a pacing strategy would be one key performance factor. By determining the position of the analysis points using the method of this study, one can obtain the split times at these points. One can then check and evaluate their pacing strategies. In addition, the method might be applied to analyses of other kinds, for example, to ascertain the ground contact position for each step of a runner and to measure the stride length per step.

Ⅴ. Summary

In this study, we specifically examined a comprehensive method for calculating the coordinates of athletics track marks. Calculation of the mark coordinates for two typical track layouts was also presented. Furthermore, two examples of analysis-point position identification were demonstrated based on the calculated mark coordinates. The identification was confirmed to be sufficiently accurate for race analysis purpose. The methods and the demonstration data presented herein are expected to facilitate future race analyses and to contribute to the advancement of sports science.

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